Technical Report No. 89-05

Potential impact of snow cover of Cape Churchill Wildlife Management Area on a proposed release of muskoxen *(Ovibos moschatus)*

By Soprovich, Daniel W. 1989

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ABSTRACT

A study area located approximately 65 km southeast of Churchill has been selected as a potential release area for muskoxen (Ovibos moschatus). Snow depth and integrated Ram hardness were measured across 6 beach ridges and within a fen. Sampling was conducted within 3 plant communities at approximate monthly intervals between 29 January and 29 March 1987. Snow was relatively shallow near the apex and deep near the periphery of beach ridges. Integrated Ram hardness was generally low near the apex and high near the periphery of beach ridges. Snow depth and integrated Ram hardness varied between transects, sampling periods, and plant communities and were highly variable within the fen community. Snow depth and integrated Ram hardness exhibited greater variability at the third as compared to the first sampling period. Integrated Ram hardness was ≤400 kg·cm at ≥31% and snow depth ≤20 cm at >50% of the stations within the ridge community at any sampling period. Integrated Ram hardness was ≤400 kg·cm and snow depth ≤30 cm at 0% and 4% of the stations within the fen and modified communities respectively at the last sampling period. Snow depth and integrated Ram hardness related as a curvilinear function to height below apex for beach ridges. Slope and/or depressions/apices also influenced snow depth and integrated Ram hardness as did aspect. A surface crust impacted integrated Ram hardness at sampling period 3. A strong curvilinear relationship existed between integrated Ram hardness and snow depth for beach ridges. The rate of increase of integrated Ram hardness with increasing snow depth differed between sampling periods which suggests that snow depth as an index to the energetic cost of foraging varies temporally and should be used cautiously. A weak linear relationship between integrated Ram hardness and snow depth existed at sampling periods 2 and 3 within the fen community.

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INTRODUCTION

Muskoxen (Ovibos moschatus) were found within the present boundaries of Manitoba prior to the impact of European man upon their distribution and abundance (Burch 1977, Fig. 1). Interest in re-establishment of the muskox as a component of the Manitoba fauna led representatives of the Manitoba Wildlife Branch and the Northwest Territories Department of Renewable Resources to discuss the availability of muskoxen for transplant.

An area of potential release was selected southeast of Churchill (Fig. 1). Although outside the known historical range (an apparent extralimital record exists (Preble (1902)), this study area was selected on the basis of habitat important to muskoxen, opportunity to land large aircraft, and proximity to support services in Churchill. An additional reason for selection of the study area was that it is within the Cape Churchill Wildlife Management Area, a geographic unit in which land-use is administered by the Manitoba Wildlife Branch.

A cover map of the Cape Churchill Wildlife Management Area was prepared using 27 June 1980 and 3 August 1984 Landsat Satellite data. Plant species frequency data were collected within several habitat types between 29 July and 8 August 1986 allowing limited assessment of the cover map and providing quantitative information about the study area (Rewcastle 1986).

Winters of excessive snowfall, often in combination with the formation of ice layers, may lead to substantial mortality of muskoxen (Vibe 1967, Parker et al. 1975, Smith 1984). Representatives of both government agencies were concerned that snow conditions within the study area might be excessive for muskoxen. The objectives of this study were to examine snow conditions within the beach ridge and adjacent fen plant communities of the study area and to assess the potential impact of this important component of the environment upon the proposed release of muskoxen. Beach ridges were examined because it was hypothesized that the plants found on these ridges would be more available to muskoxen due to relatively low snow accumulation. The fen community was examined because graminoids found in such communities are extensively utilized by muskoxen (Klein and Staaland 1984, Thomas and Edmonds 1984).

STUDY AREA AND METHODS

The study area (57°45′ and 58°25′ N latitude; 93°40′ and 94°30′ W longitude) encompasses 65 km of the Hudson Bay coast and extends approximately 30 km inland (Fig. 1). The town of Churchill is located approximately 65 km northwest.

Cover maps based on interpretation of photographs (Ritchie 1962) and Landsat Satellite data exist for the study area. Limited field data (Rewcastle 1986; D. Soprovich, Man. Wildlife Branch, unpubl. data) suggest that both cover maps have limitations. The Cape Churchill Wildlife Management Area Cover Map indicates that dry fen (<5%), saturated fen (≈70%), willow (<5%), black spruce (≈5%), and beach ridge complex (≈20%) habitat types occur in the study area. The saturated fen is dominated by members of the Cyperaceae family (Carex sp., Eriophorum sp., Scirpus sp.) while the dry fen is dominated by mosses and Carex sp. in the fens and small lakes and by lichens and ericaceous species on the hummocks, tussocks, and palsas (Rewcastle 1986). The plant association described as lichen-heath (Neal and Kershaw 1973a,b; Kershaw and Rouse 1973; Pierce and Kershaw 1976) and sedge meadow (Kershaw 1974) best describe the ridge and fen communities which comprise the majority of the beach ridge complex. Coastal salt marsh (Kershaw 1976) and dwarf birch-willow (Ritchie 1960) communities are also found in the beach ridge complex.

Relict beach ridges offer the most significant relief within the coastal area. Snow characteristics were measured along transects perpendicular to the direction of the beach ridges and across anticipated gradients. The initial objective was to collect measurements across each beach ridge and well into the adjacent fen community on both sides of the ridge.

The cover map showed that beach ridges extended the length of the study area from the coast to 6 km, on average, inland. The first transect was randomly selected within the northern 13 km of beach ridge complex and the location transcribed to a MSS color print (Landsat data). Four additional transects were each located 13 km from the previous transect on the color print.

Transects were located and permanent markers erected between 29

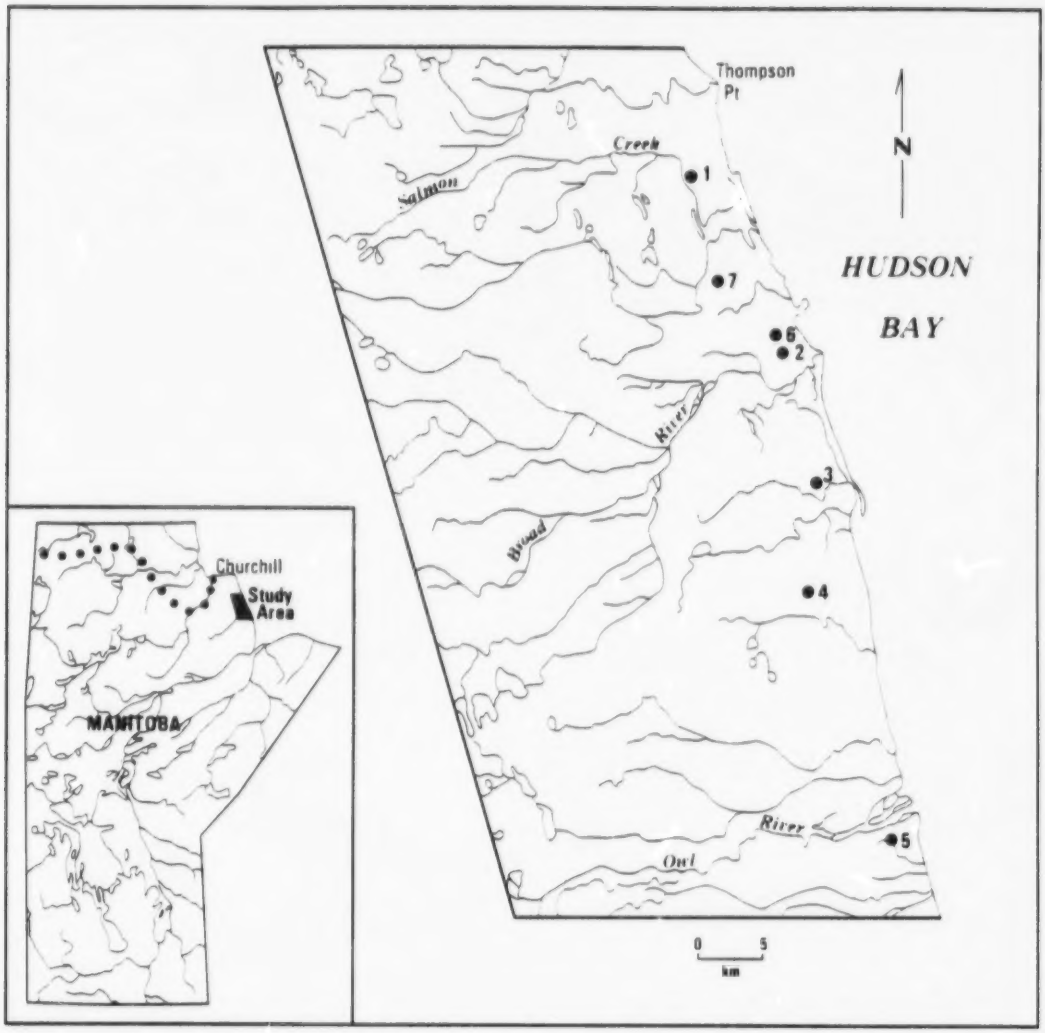

FIG. 1. Location of Snow transects 1 to 7 within the study area. Inset map illustrates location of study area relative to Churchill. The dotted line on the inset details the approximate southern limit of muskoxen distribution prior to the impact of European man (from Burch 1977).

January and 1 February 1987. The large scale of the MSS color map and the snow-covered topography made it almost impossible to locate the transects with the use of the map. The map was then used to calculate the distance between each transect and the Broad River (transects 1-4) or the Owl River (transect 5). Each transect was located by driving a snowmobile the appropriate distance, as measured by the odometer, from these two easily located points of reference.

All transects were not located equidistant apart because well-defined ridges were virtually absent within the southern 40% of the study area. Where a ridge did not exist, travel occurred in the direction in which it was expected to find the closest ridge, until successful. Given the inability to utilize the MSS color map, the location of transects relative to the distance from the coast was not random but rather reflected the opportunity to find beach ridges and a desire to examine ridges exhibiting different physical characteristics. Under these circumstances, beach ridges were not selected randomly and in a strictly statistical sense, data generated relative to snow conditions is not broadly applicable (i.e., inferences generated relative to snow conditions within the study area would likely be somewhat biased).

Transects 6 and 7 were added as time and materials were available. Transect 6 was located completely within the fen community. Transect 7 data assisted in detection of any gradient in the snow characteristics from north to south.

Each transect was intended to be permanent. Initially, stations were to be marked at 5 m intervals; however, the greater than anticipated width of the ridges and the lack of snow in the vicinity of the apex dictated that most sampling stations were marked at 10 m intervals with the greatest interval being 30 m across an apex. Stations were marked by hammering a 91.4 cm x 2.5 cm galvanized rod as far as possible into the ground. Hollow plastic poles >2 m high and calibrated at 0.5 cm intervals were inserted over the metal rods and pushed into the snow to ground level.

Snow measurements were taken at 5 m intervals. Sampling occurred at the site for those stations marked by a pole; for those stations without a pole, sampling was carried out at measured 5 m intervals between adjacent poles. Snow depth was measured at each station either directly from the

tape on the pole or with a meter stick. In those cases where it appeared that snow depth was influenced by the presence of a pole (eg., a slight drift on the leeward side of a pole), the snow depth measurement was adjusted subjectively to account for this apparent influence.

A measure of the resistance of the snow column to penetration was collected with a Rammsonde penetrometer (Lent and Knutson 1971). The Rammsonde penetrometer will yield a measure of the work (kg•cm) required to penetrate to ground level. This penetrometer is both simple and quick to use and has potential application to measurement of the energetic cost of foraging. Rammsonde measurements were collected at each station adjacent and to the north of where snow depth was collected. Snow depth and Rammsonde measurements were collected during 3 sampling periods: 29 January to 1 February, 25 February to 26 February, and 28 March to 29 March.

The Rammsonde penetrometer was borrowed and had been built from obtained specifications. Unfortunately, it was not recognized that the builder had diverged from these specifications until the data had been collected. This penetrometer differed from the specifications for a number of characteristics, the majority of which would have influenced the performance negligibly. The borrowed penetrometer was lighter (1262 g versus 1358 g for an instrument in current use in Alaska) and utilized different small (1025 g versus 1000 g in specification) and large (2842 g versus 3000 g in specification) hammers. The greater cone width (4.2 cm versus 4.0 cm) of the borrowed Rammsonde would have resulted in slightly inflated measures of integrated Ram hardness (kg•cm). Consequently, measurements have been treated as modified Rammsonde measures.

Physical and vegetation characteristics were measured along each transect between 2 August and 5 August 1987. The height above base (base defined as lowest elevation on each transect) was measured for each station with a surveyors instrument. All galvanized rods had fallen over and each was repositioned and hammered as far as possible into the ground. The distance between adjacent stations was measured. Transects were straight and the distance between transect ends was similar to that from the winter measurements (the transect distance varied between 2.7% and 3.9% greater when measured during the summer, a result likely due in part to the filling in of depressions during the snow period) indicating that rods had not moved

to any great extent. Galvanized rods generally appeared to have fallen over with their base near their point of entry into the ground; in several cases near the apex of the ridges, rods appeared to have moved somewhat. In such cases, stations were positioned near where they had been found because it could not be determined if their location resulted from the rod having moved or if the rod had been incorrectly located during the winter. Any errors introduced by this apparent problem would be relatively insignificant given the variability in elevation and vegetation across the beach ridges. At each station, plant species frequency and an ocular estimate of cover for each species was collected within a 0.25 m x 0.25 m quadrat centered about the station.

Means were compared by a large sample test (z statistic) or Student's t test with variances compared by an F statistic (Mendenhall 1971). An F statistic (ANOVA) was used to assess linear association (Kleinbaum and Kupper 1978).

RESULTS

Physical characteristics of beach ridges

Beach ridges varied considerably relative to height, width, and slope (Fig. 2). The elevation was similar on both sides for some ridges (eg., transect 3) but considerably lower on the Hudson Bay side for others (eg., transect 5). The beach ridge sampled by transect 1 was relatively high and wide. In addition, the data depicted by Fig. 2 are incomplete for this ridge in that sampling did not occur far enough down on the Hudson Bay side (i.e., sampling did not continue to a levelling of the elevation therefore the height of the apex is understated). The data for this ridge are also incomplete in that they represent only a portion of a two-ridge complex. The second ridge of this two-ridge complex was located on the side farthest from Hudson Bay and had an apex higher than the apex of the portion depicted by Fig. 2. Although it appears that a constant elevation had been obtained, transect 5 did not adequately sample the ridge into the adjacent fen community. The ridge sampled by transect 3 was adequately sampled to the fen community on both sides of the ridge. Elevation changed only 13 cm between the ends of the transect (6) in the fen community.

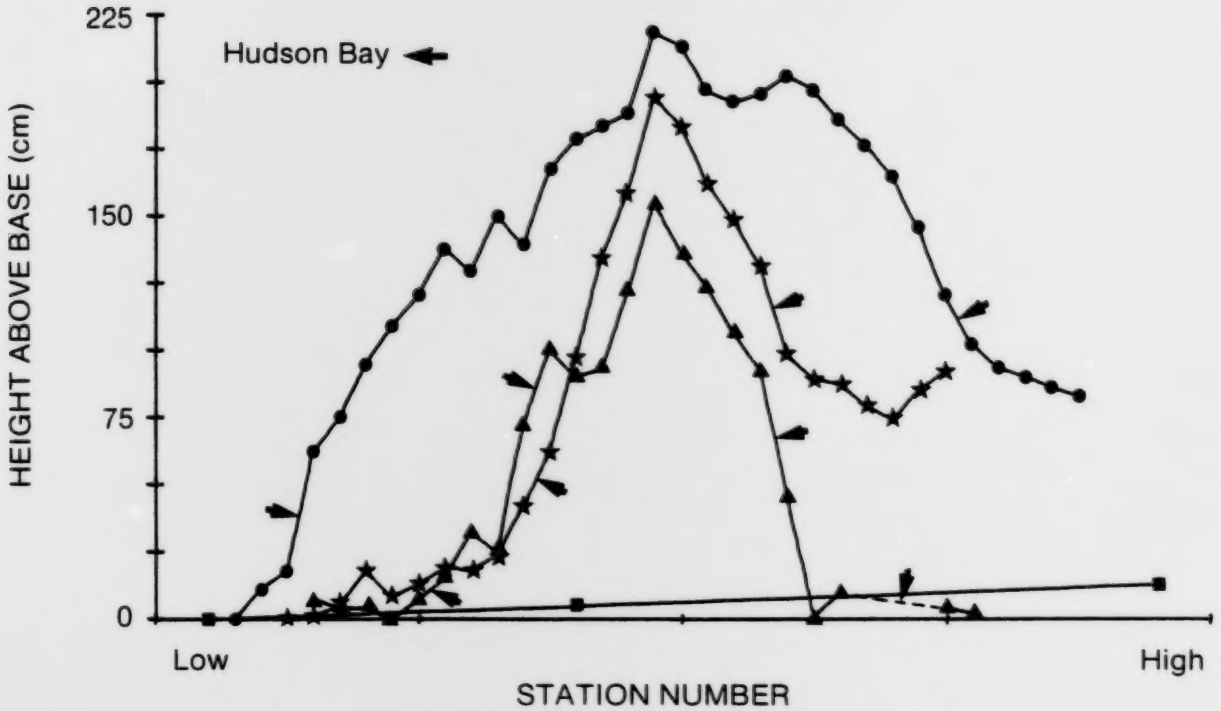

FIG. 2. Profiles of several beach ridges (● , transect 1; ▲, transect 3; ★, transect 5) and one fen (■ , transect 6). Arrows indicate approximate location of change in vegetation community. The dashed line for transect 3 represents stations located in a pond. Stations are located approximately five meters apart.

Transect 2 did not begin far enough from the apex of the ridge because the adjacent sedge community was not sampled (Fig. 3). The sedge community was sampled on the other side of the apex (stations 29-31); however, representation by this community was likely due to these stations being located within a depression between 2 ridges (i.e., the ridge sampled represented only 1 ridge of a two-ridge complex). The apex of the second ridge of this two-ridge complex had an elevation of approximately 230 cm above base.

It appears that transect 4 did not extend far enough on the side opposite Hudson Bay to reach a relatively constant elevation (Fig. 4). It is believed that further measurements would have indicated that the land on this side of the apex was higher in elevation than that on the Hudson Bay side. The sedge community was not sampled on either side of the beach ridge. This may have resulted from the transect beginning and ending too close to the apex of this ridge (further sampling should have been conducted on the side of the apex farthest from Hudson Bay). The transect ended at the edge of a wetland and it is possible that the sedge community did not exist adjacent to this ridge due to considerably more wetland habitat and less relief than areas adjacent to the other ridges examined (see following comparison of transect 4 within Table 1).

Transect 7 extended into the adjacent sedge community on the side of the apex closest to Hudson Bay (Fig. 5). The transect did not extend to the sedge community on the opposite side of the apex although this community was found within the depression sampled by station 17.

Transects were located between 12.6 km north and 35.7 km south of the mouth of the Broad River (Table 1). The distance from the Hudson Bay coast and elevation above sea level differed between transects. The different contour levels (elevation above sea level) in Table 1 result from different contour levels being used on different topographic maps. Orientation of the beach ridges varied considerably from almost north (9° west of north) to northwest (46° west of north). The cover type, as defined by the Cape Churchill Wildlife Management Area General Land Cover Map, was beach ridge complex (well defined ridges) for the majority of the transects. Transect 4 was located near the saturated fen and transect 5 within the beach ridge complex (gently undulating) cover types. The

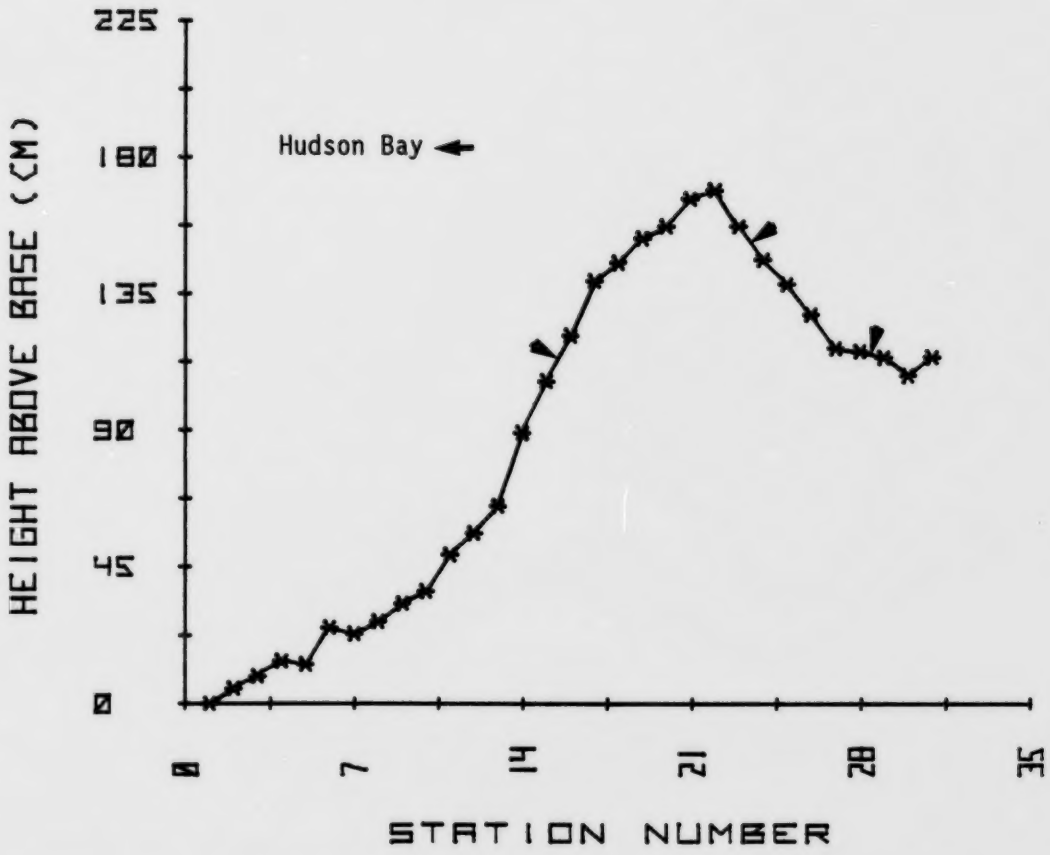

Fig. 3. Profile of beach ridge sampled by transect 2. Arrows indicate approximate location of change in vegetation community.

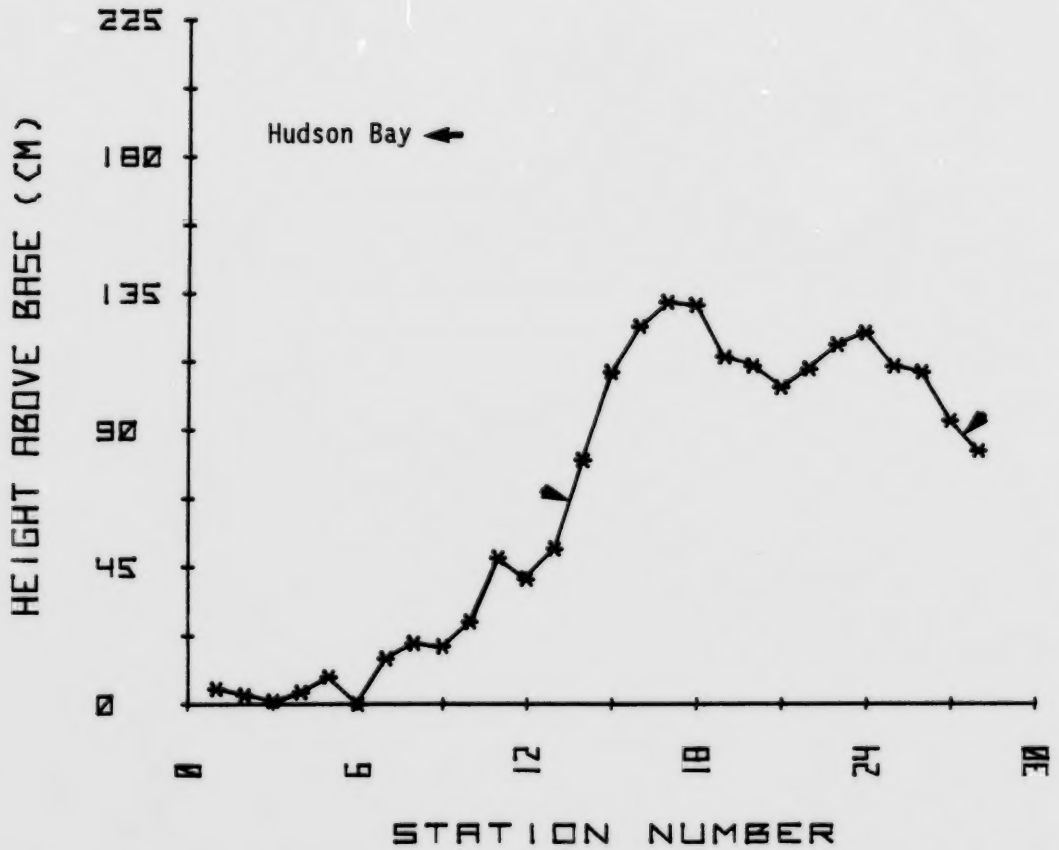

Fig. 4. Profile of beach ridge sampled by transect 4. Arrows indicate approximate location of change in vegetation community.

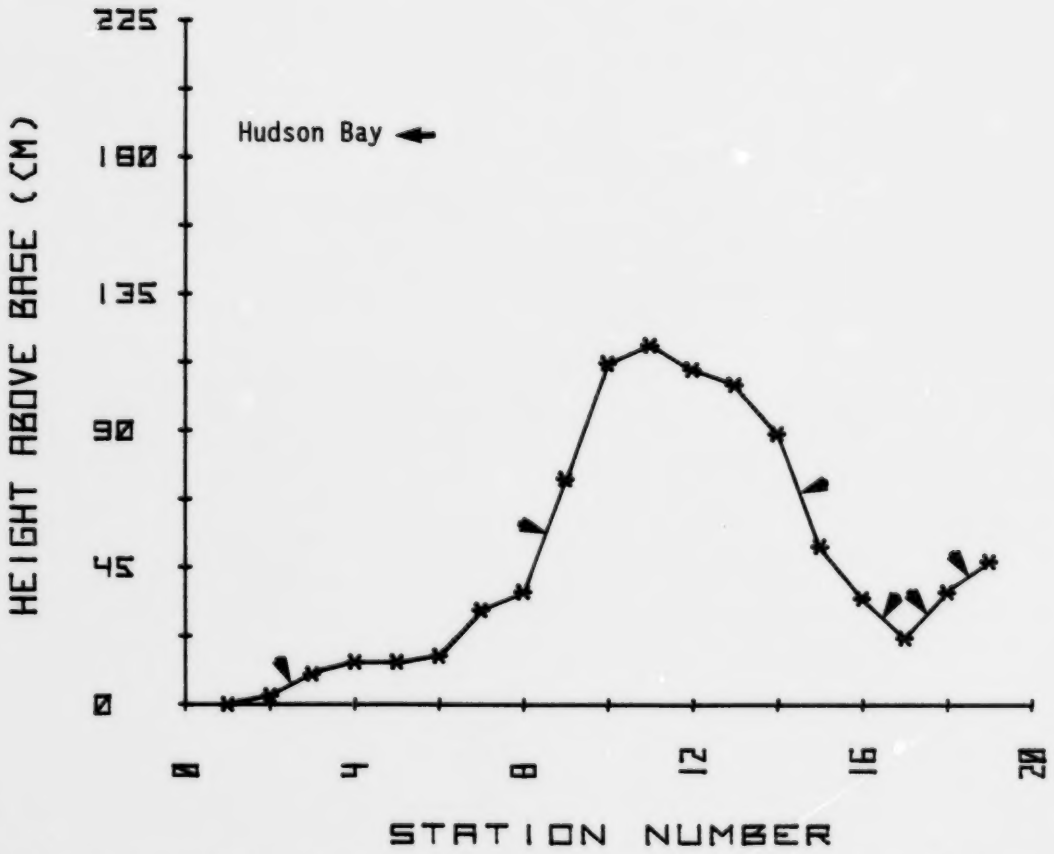

Fig. 5. Profile of beach ridge sampled by transect 7. Arrows indicate approximate location of change in vegetation community.

saturated fen plant community sampled by transect 6 was located within the beach ridge complex (well defined ridges) cover type. Saturated fen comprised a large portion of this cover type thus illustrating the crude level of precision of the Cape Churchill Wildlife Management Area General Land Cover Map.

Table 1. Physical and habitat characteristics of 6 beach ridges and 1 fen examined within the study area. Information from topographic maps and Cape Churchill Wildlife Management Area General Land Cover Map.

Transect number	Distance north or south of Broad River (km)	Distance from coast (km)	Elevation above sea level (m)	Orientation[a] (°)	Cover type[b]
1	12.6 N	3.3	7.6-15.2	23 W	BR
2	0.0	2.1	7.6-15.2	46 W	BR
3	10.0 S	2.3	7.6-15.2	9 W	BR
4	17.7 S	4.3	10.0-20.0	23 W	SF/BR
5	35.7 S	2.4	0.0-10.0	32 W	BR(G)
6	1.3 N	1.7	7.6-15.2	32 E	BR
7	5.3 N	3.9	7.6-15.2	46 W	BR

[a]Orientation is the angle in degrees between the long axis of a beach ridge and true north; orientation as defined can be either east or west of north; for transect 6, which is within the fen community, orientation is the same as the direction of the transect.
[b]BR refers to beach ridge complex (well defined beach ridges); BR(G) refers to beach ridge complex (gently undulating); SF refers to saturated fen.

Vegetational characteristics

A plant community (ridge community) dominated by Dryas integrifolia, Salix reticulata, Rhododendron lapponicum, Arctostaphylos rubra, Vaccinium uliginosum, and several foliose lichens characterized the highest elevations on all beach ridges. A fen community dominated by Carex aquatilis, Carex sp., Eriophorum sp., Betula glandulosa, and willows (Salix sp.) up to 1 m in height was found on both sides of the beach ridges. Habitat between the ridge and fen communities contained elements of both communities at varying proportions relative to elevation. This community contained peat hummocks and exhibited the greatest species diversity and is

subsequently referred to as the modified community. The number and proportion of stations located within each of these communities is detailed by transect in Table 2.

Table 2. Number and proportion of stations located within each of the 3 plant communities for transects 1-7. Stations located within wetlands not included.

Transect number	Ridge		Modified		Fen	
	n	%	n	%	n	%
1	25	76	8	24		
2	8	26	20	65	3	10
3	9	39	7	30	7	30
4	14	50	14	50		
5	9	35	17	65		
6					37	100
7	7	37	9	47	3	16

The beach ridges sampled by transects 1, 4, and 5 did not include any stations within the fen community. A small proportion of the fen community was sampled by transects 2 and 7 while 30% of the stations from transect 3 were located within the adjacent fen community. The fen community was sampled on both sides of the beach ridge by transects 3 and 7 while transect 2 only sampled the side of the ridge farthest from Hudson Bay. The relative proportion of ridge and modified communities sampled by each transect was variable.

Snow depth

Snow depth exhibited the typical shallowness near the apex for the ridge examined by transect 2 (Fig. 6). Snow appears to have been deeper on the side opposite Hudson Bay, particularly for period 3. This may have related to the influence of the adjacent ridge of this two-ridge complex. This also may have related to an interaction between the orientation of this ridge (northwest) and prevailing winds between periods 2 and 3. Snow depth

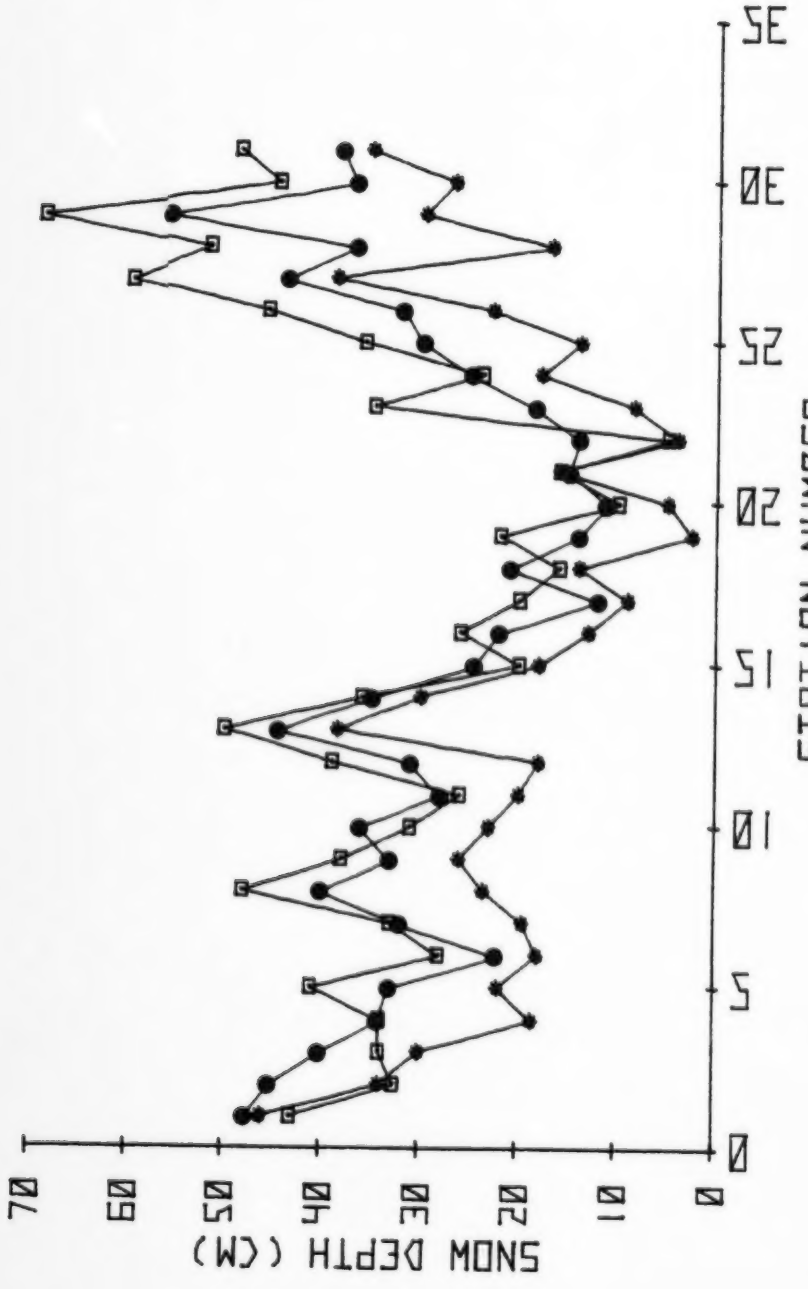

Fig. 6. Snow depth on 29 January (●), 25 February (●), and 28 March (⊡) for transect 2.

does not appear to have been substantially influenced by solar radiation because the stations on the side of the apex opposite Hudson Bay would have received the greatest exposure.

Snow depth across the beach ridge sampled by transect 1 (Fig. 7) was atypical in that it was highly variable across the apex. This variability likely resulted in part from the several depressions near the apex (eg., station 12, all periods and stations 19-21, period 3 in particular). Relatively deep snow was recorded consistently near the ends of the transect. The deep snow recorded at the third sampling period at the far end of the transect may have resulted from snow accumulating in this depression between ridges.

Snow depth across the other beach ridges exhibited the typical shallowness across the apex (Figs. 8-11). Snow depth across the apex of the beach ridge sampled by transect 3 was influenced by the presence of a depression near stations 11 and 12 (Fig. 2). Near the end of the transect (both before and after the wetland between stations 21 and 25), snow depth may have been influenced by the depression occupied by the wetland.

Snow depth across the apex of the beach ridge sampled by transect 4 (Fig. 9) was also influenced by the presence of a depression (stations 19-23, Fig. 4). The beach ridge sampled by transect 5 did not have significant depressions near the apex (Fig. 2) and snow across the apex was uniformly shallow as a result (Fig. 10). It appears that depth was beginning to stabilize at both ends of this transect; however, further data beyond the ends of the transect would be required to verify this statement. The beach ridge sampled by transect 7 did not have significant depressions near the apex (Fig. 5) and snow across the apex was relatively shallow as a result (Fig. 11). The apparent greater depths on the side of the apex opposite to Hudson Bay may have resulted, in part, from the influence of a depression (station 17, Fig. 5) or may have related to interaction between orientation of this ridge (northwest) and prevailing winds (similar to transect 2 - note that both transect 2 and 7 are oriented northwest and are near each other).

Snow depth across the fen (Fig. 12) was relatively constant as compared to the beach ridges. Snow depth was most variable for the stations closest to the beach ridge and farthest from Hudson Bay in the fen community. One end of this transect was located approximately 45 m from a

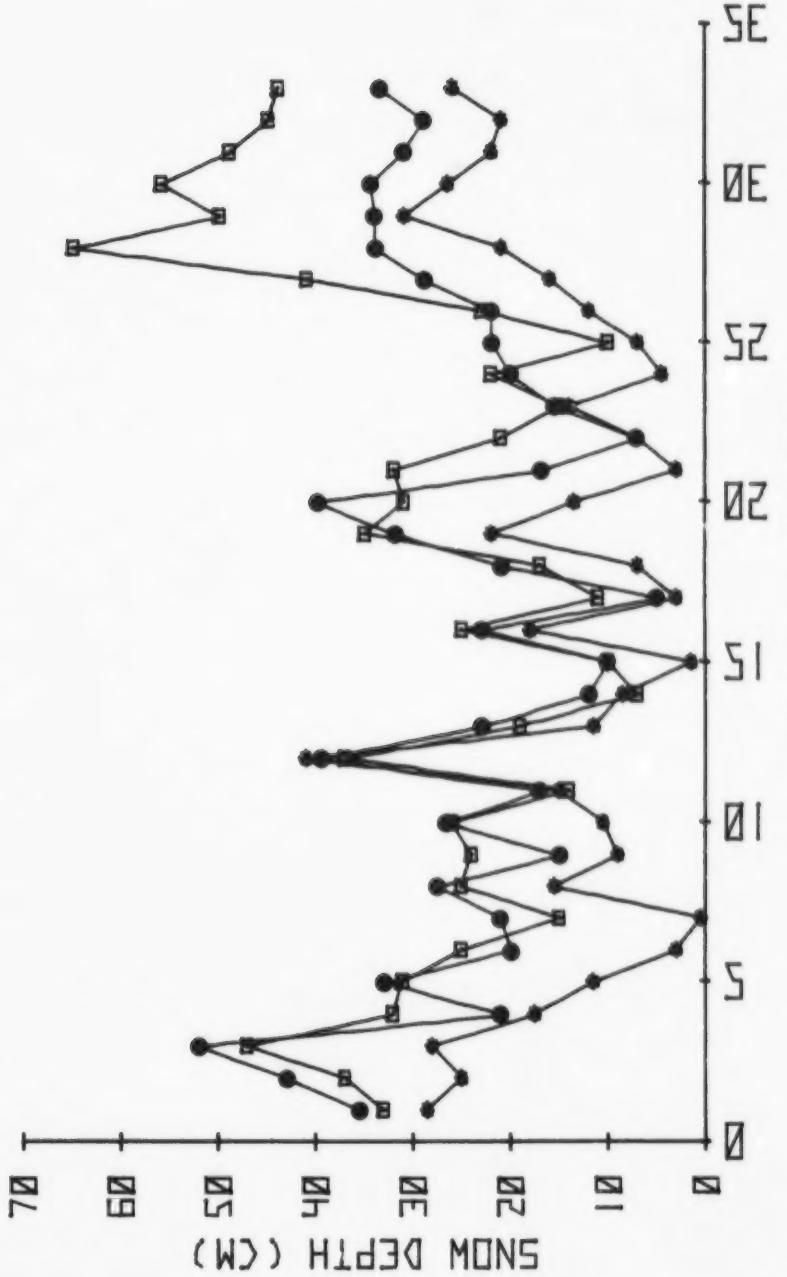

Fig. 7. Snow depth on 29 January (●), 25 February (●), and 28 March (⊡) for transect 1.

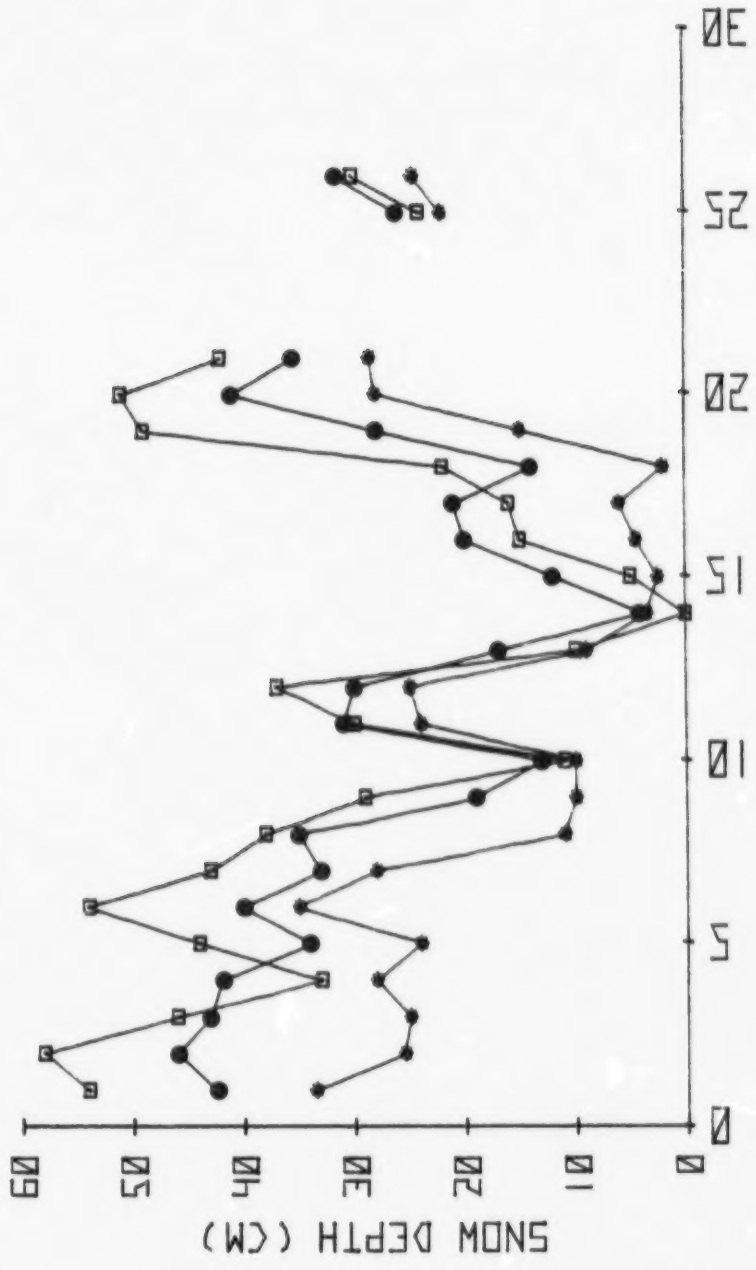

Fig. 8. Snow depth on 31 January (●), 26 February (●), and 29 March (▣) for transect 3.

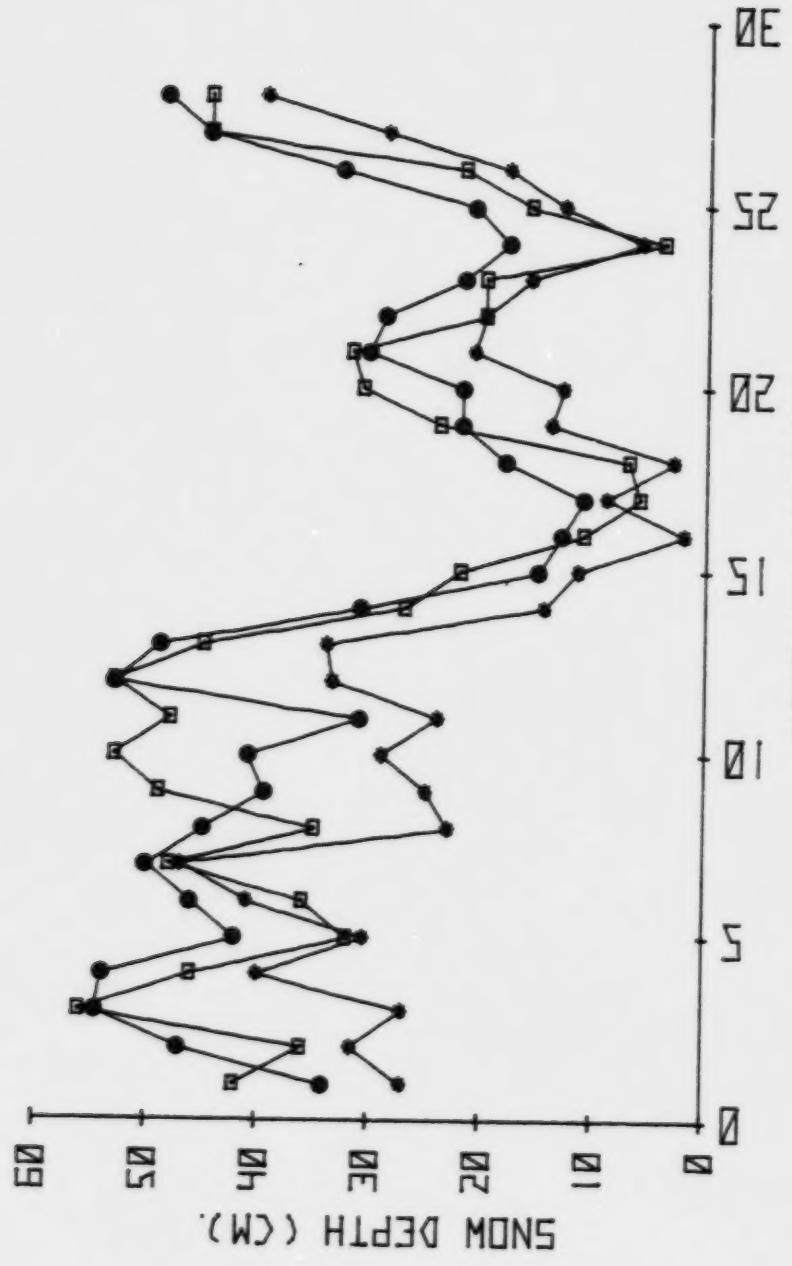

Fig. 9. Snow depth on 30 January (*), 26 February (●), and 28 March (⊡) for transect 4.

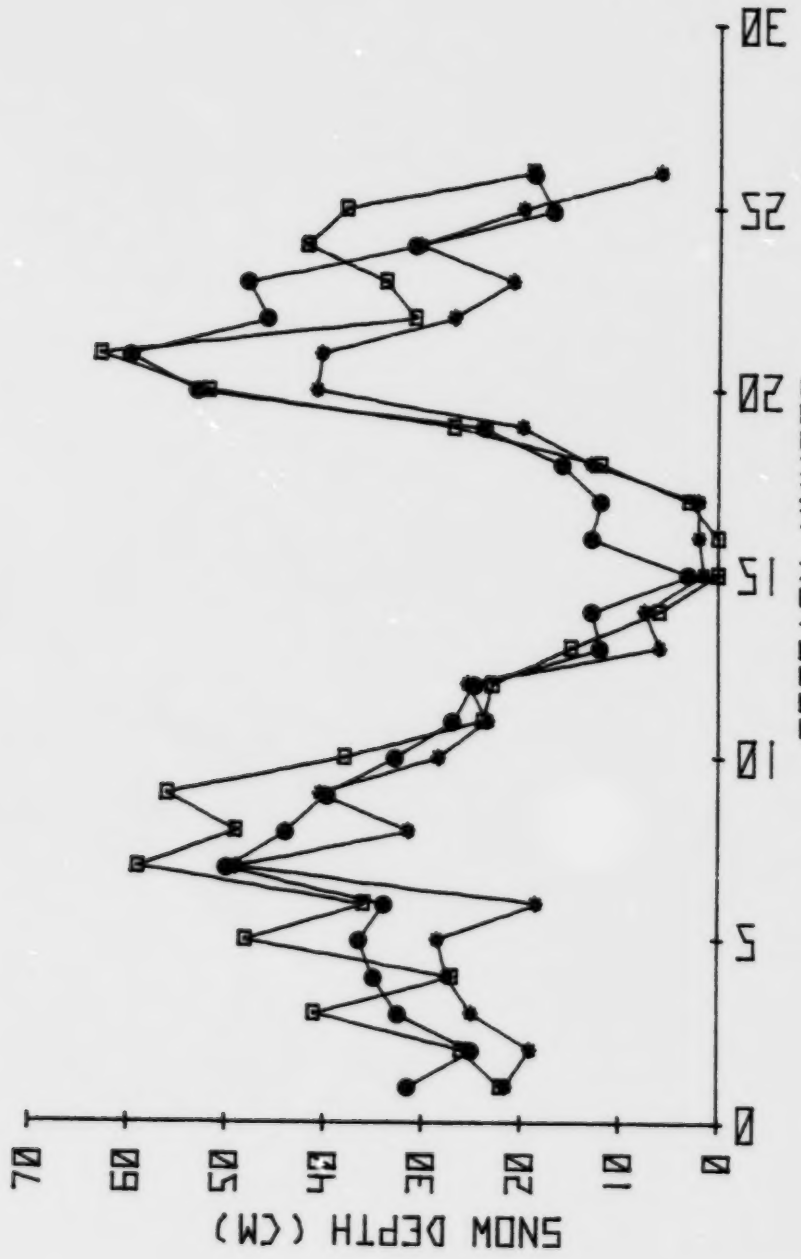

Fig. 10. Snow depth on 30 January (●), 26 February (●), and 29 March (⊡) for transect 5.

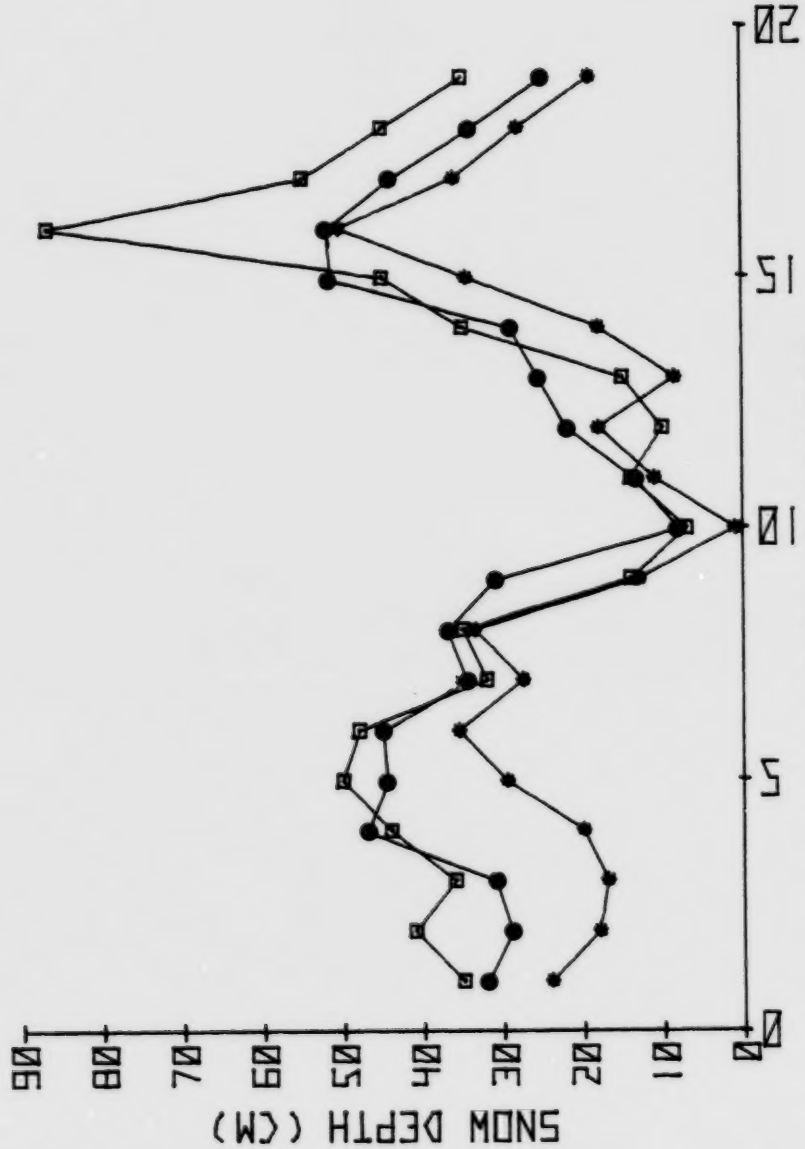

Fig. 11. Snow depth on 1 February (✱), 25 February (●), and 28 March (▣) for transect 7.

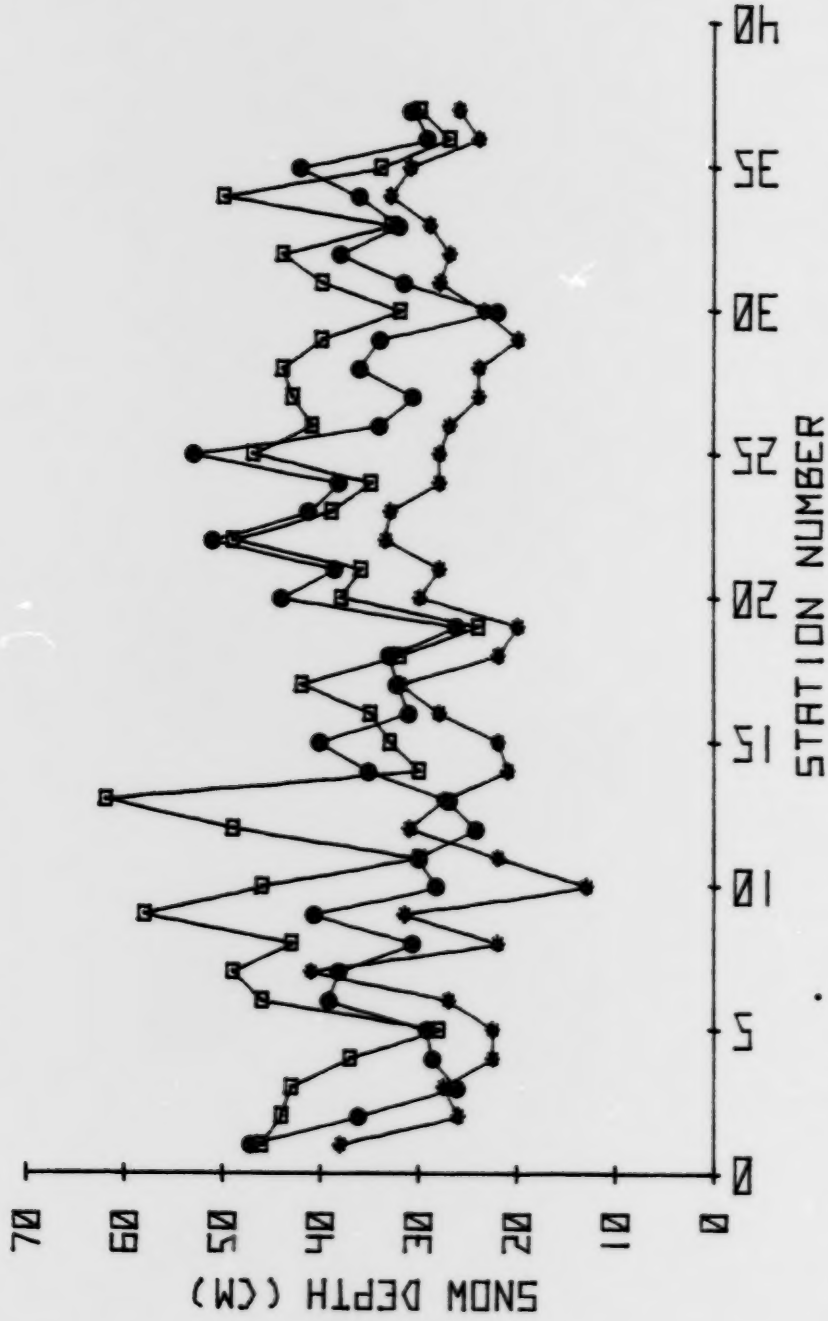

Fig. 12. Snow depth on 31 January (*), 25 February (●), and 28 March (⊡) for transect 6.

beach ridge. There was no relationship between snow depth and distance from the beach ridge on 31 January ($r = -0.01$, $n = 37$, $P > 0.25$), 25 February ($r = -0.11$, $n = 37$, $P > 0.25$), or 28 March ($r = -0.26$, $n = 37$, $P > 0.10$). This suggests that the adjacent beach ridge did not influence snow depth in the fen community (although the great variability on one end may have resulted from proximity to the ridge).

Temporal and community variation in snow depth

The transects across the beach ridges were not long enough to adequately sample snow within the fen community and snow depth within this adjacent community was likely influenced by the beach ridge. For these reasons, the data relative to the fen community emanate solely from transect 6.

Snow depth within the ridge community was lower at the first sampling period (Table 3) than at the second ($P < 0.005$) and third sampling periods ($P < 0.005$). Snow depth within the fen and modified communities for each period was greater than snow depth within the ridge community at any period.

Table 3. Mean snow depths (cm) for 3 vegetation communities sampled from 29 January-29 March 1987.

Sampling period	Ridge (n=72)		Fen (n=37)		Modified (n=75)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
29 Jan-1 Feb	11.8^{a}	$8.5^{a,d}$	26.9^{c}	5.4^{c}	27.3^{c}	$9.0^{a,e}$
25 Feb-26 Feb	20.9^{b}	$9.5^{a,f}$	34.6^{d}	$7.1^{c,d,e}$	37.8^{e}	$9.1^{a,b,e}$
28 Mar-29 Mar	20.3^{b}	$12.5^{b,g}$	$40.0^{e,f}$	$8.5^{a,e}$	41.6^{f}	$11.3^{f,g}$

^{a,b,c,d,e,f,g}Mean snow depths and standard deviations with the same letter are not significantly different (z test, F test, $P > 0.05$).

Snow depth increased from the first to the second sampling period ($P < 0.005$) and from the second to the third sampling period ($P < 0.005$)

within the fen community. Within the modified community, snow depth had increased by the second sampling period ($P < 0.005$) and increased from the second to the third sampling period.

Snow depth was greater in the modified community as compared to the fen community for the second sampling period. No difference existed between these 2 communities when other sampling periods were examined. The variance (and standard deviation) was greater for the third sampling period as compared to the first sampling period for the ridge, fen, and modified communities.

Snow depth within the ridge and modified communities

The mean snow depth at the stations within the ridge community increased from the first to second sampling period for each transect which sampled beach ridges (Table 4). The mean snow depth at the stations in this community decreased from the second to third sampling period for all transects with the exception of transects 1 and 2 which were located in the northern portion of the study area. The mean snow depth at the stations in the ridge community of transect 7, also located in the northern portion of the study area, decreased from sampling period 2 to 3. The mean snow depth at the stations within the modified community increased from sampling period 1 to sampling period 2 to sampling period 3 for all transects with the exception of transect 4.

Snow depth was greater (two-tailed test, $t = 2.23$, $P < 0.05$) at transect 4 than transect 2 for the second sampling period. This likely results from structural differences between the 2 transects (see Figs. 3,4). A depression was located in the middle of the ridge sampled by transect 4 and snow within this depression was relatively deep ($\bar{x} = 25.1$ cm for stations 19-23). The greatest snow depths within the ridge community were recorded from the peripheries of this transect (31 cm at station 14, 33 cm at station 26, and 45 cm at station 27). These relatively great depths may have resulted from structural characteristics near the periphery of the ridge community (eg., the location of station 14 above a depression, the location of stations 26 and 27 near a pond). The mean snow depth was not different between other transects for the first, second, or third sampling periods at $P = 0.05$ (several were different at $P < 0.10$).

Table 4. Means and standard deviations for snow depth (cm) within the ridge and modified communities and the combination of these 2 communities for transects which sampled beach ridges.

Sampling period	Transect number	Community: Ridge $\bar{x}$	Ridge SD	Modified $\bar{x}$	Modified SD	Ridge and Modified $\bar{x}$	Ridge and Modified SD
29 Jan-1 Feb	1	11.7	8.6	26.0[a]	3.3	15.2	9.8
	2	9.0	5.0	24.8[a]	8.7	20.3	10.6
	3	9.6	8.9	22.2[a]	10.0	15.1	11.1
	4	13.6	7.3	32.3[b]	7.3	22.9	11.9
	5	13.2	13.4	26.9	10.0	22.3	12.8
	7	12.6	6.5	30.7	9.7	22.8	12.4
25-26 Feb	1	22.3	9.2	36.6[a,c]	7.5	25.8	10.7
	2	15.9[a]	4.1	34.7[a]	7.2	29.3	10.7
	3	18.0	8.7	33.1[a]	7.6	24.6	11.1
	4	23.6[b]	9.2	45.4[b]	7.2	34.5	13.7
	5	19.0	14.4	35.9[a,c]	11.2	30.0	14.6
	7	22.0	8.4	41.8[b,c]	7.9	33.2	12.8
28-29 Mar	1	24.5	12.4	45.1	7.3	29.5	14.4
	2	18.8	9.3	37.6[a]	10.1	32.2	13.0
	3	16.2	11.8	43.7	8.6	28.3	17.4
	4	20.5	11.4	44.6[b]	7.5	32.5	15.5
	5	15.3	16.8	38.4	13.2	30.4	18.1
	7	18.6	11.6	46.9	16.3	34.5	20.1

[a,b,c]For a sampling period in a community, mean snow depths with different letters are significantly different (t test, $P \leq 0.05$).

The mean snow depth differed from transect to transect within the modified community (Table 4). Snow depth within this community was consistently high for transect 4. Snow depth at sampling period 1 was greater for transect 4 than for transect 1, transect 2 ($P < 0.02$), or transect 3 ($P < 0.02$). At sampling period 2, snow depth for transect 4 was greater than that for transect 1 ($P < 0.02$), transect 2 ($P < 0.01$), transect 3 ($P < 0.01$), or transect 5 ($P < 0.02$). The mean snow depth for transect 4 was greater than that for transect 2 at the third sampling period.

The mean snow depth for stations within the modified community was also consistently high for transect 7. Snow depth for transect 7 was greater than that for transect 2 and transect 3 at sampling period 2. The mean snow depth did not differ ($P > 0.05$) for other comparisons of transects at any of the 3 sampling periods.

Integrated Ram hardness

Integrated Ram hardness was highly variable across the beach ridge sampled by transect 1 (Fig. 13). Relatively low values were recorded near the apex but a number of high values were also recorded from this area. Similarly, relatively low values were recorded near both ends of the transect (eg, station 2 during periods 1 and 2, stations 32 and 33) despite snow depths at these stations being relatively high. This result is likely due to the ability of wind to modify (pack) snow as related to the degree of exposure at each station along the transect.

Integrated Ram hardness was lowest in the vicinity of the apex of the beach ridge sampled by transect 2, particularly on the Hudson Bay side of the apex at period 3 (Fig. 14). A great deal of variability was apparent across the ridge and relatively low values were recorded at stations where snow was relatively deep (eg., stations 2-6, 28). The substantial variation in integrated Ram hardness across the beach ridges sampled by transects 1 and 2 may relate to the influence of the adjacent ridge for these two-ridge complexes. Extreme values were recorded on both sides of the apex of this ridge at sampling period 3.

Integrated Ram hardness across the beach ridge sampled by transect 3 was relatively low near the apex and relatively high near the ends of the transect (Fig. 15). Integrated Ram hardness across this ridge exhibited similar changes to those apparent for snow depth (Fig. 8). The 2 stations located at the end of the transect (stations 25, 26) had relatively low integrated Ram hardness values which likely resulted from the relatively low snow depths recorded at this end of the transect and the possibility that the adjacent beach ridge did not influence integrated Ram hardness at this distance from the ridge (these 2 stations were located within the fen community). The adjacent wetland may also have exerted some influence on integrated Ram hardness at these stations. The relatively low values

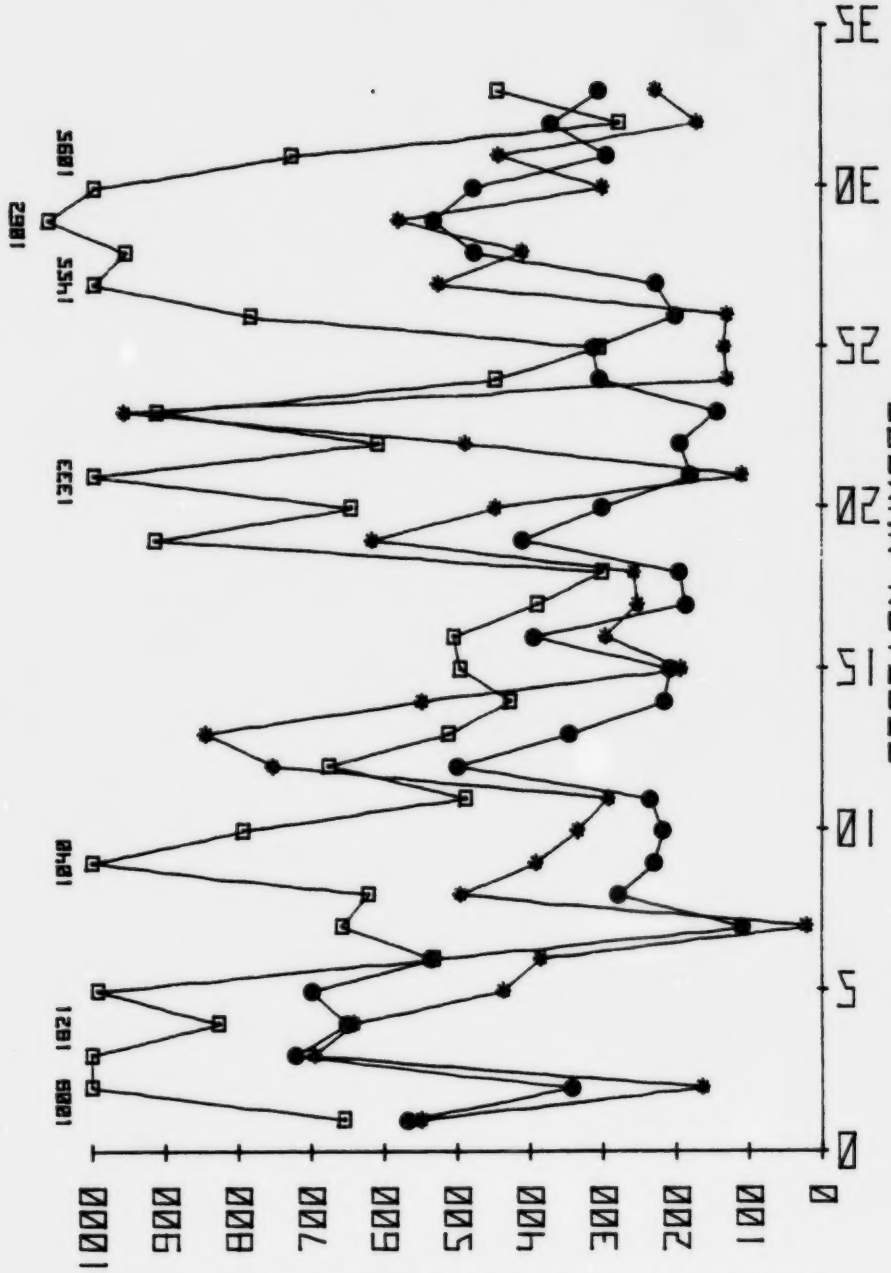

Fig. 13. Integrated Ram hardness on 29 January (✱), 25 February (●), and 28 March (▣) for transect 1.

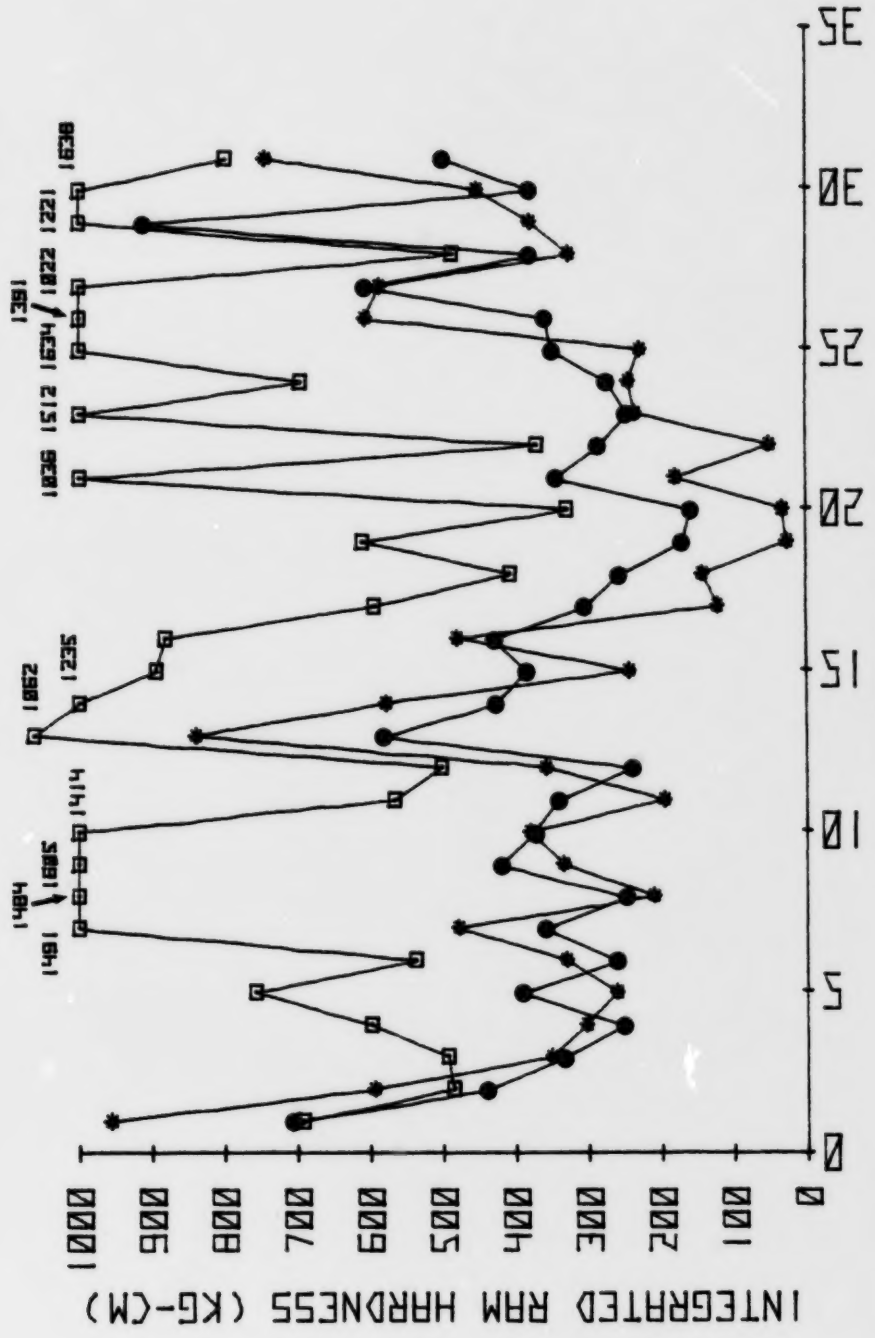

Fig. 14. Integrated Ram hardness on 29 January (●), 25 February (●), and 28 March (⊞) for transect 2.

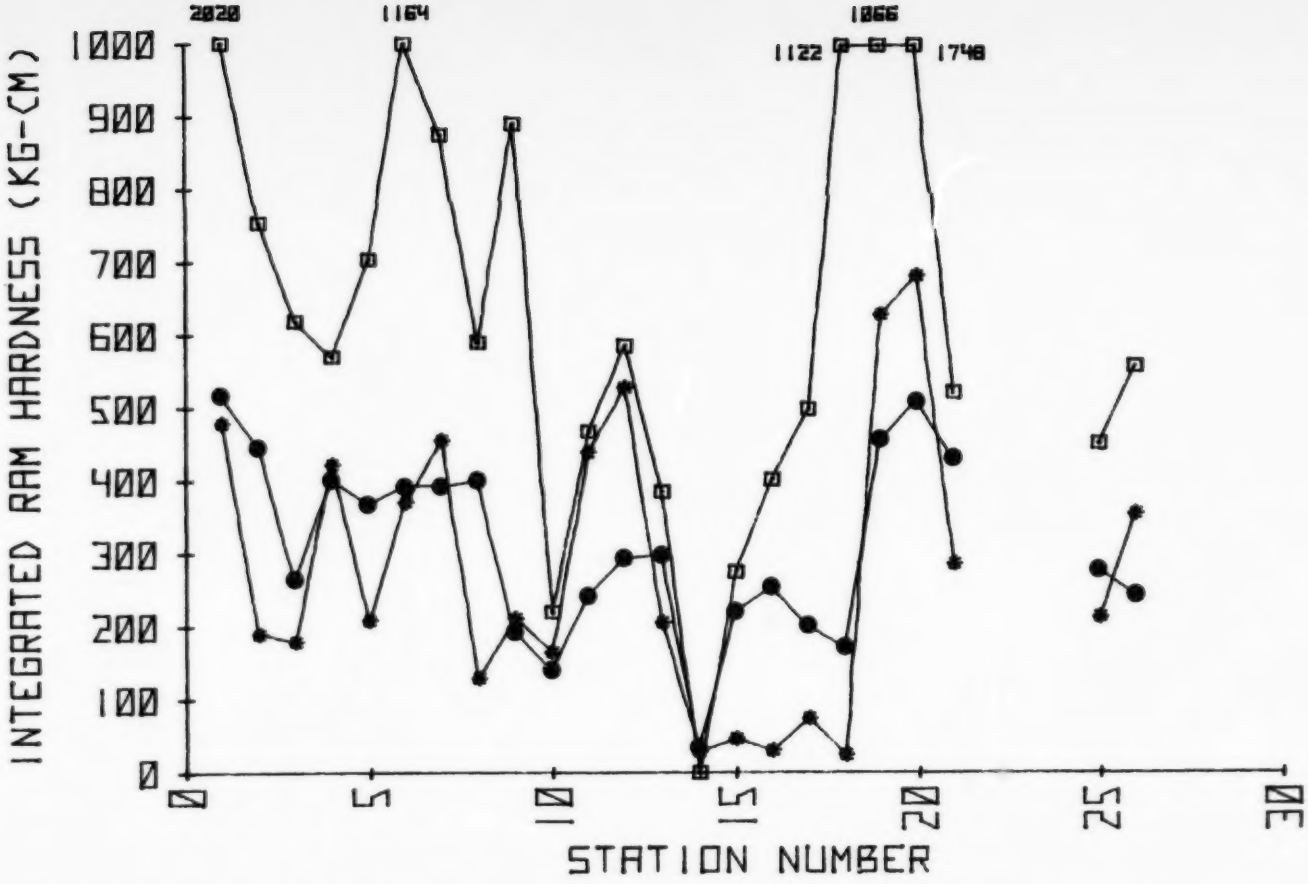

Fig. 15. Integrated Ram hardness on 31 January (✱), 26 February (●), and 29 March (⊡) for transect 3.

recorded at station 10 and the relatively high values recorded at stations 11 and 12 likely related to station 10 being located at a small apex with stations 11 and 12 being located in a depression.

Integrated Ram hardness was relatively low within several regions (stations 16-18, 24-26) of the beach ridge sampled by transect 4 at all 3 sampling periods (Fig. 16). These areas coincided with the location of the 2 apices apparent for this beach ridge (Fig. 4). An area of relatively high integrated Ram hardness values occurred within the depression between these apices. The transect did not sample integrated Ram hardness adequately on the side opposite Hudson Bay (only the last station was located within the modified community).

Integrated Ram hardness was considerably and consistently lower in the vicinity of the apex and moderate at both ends of the beach ridge sampled by transect 5 (Fig. 17). It is possible that this measure had begun to stabilize due to a lack of influence by the beach ridge. Additional sampling beyond both ends of the transect would be required to resolve this question. The very obvious variation in integrated Ram hardness across this beach ridge relates in part to this ridge being relatively simple in form (i.e., this ridge had few depressions) and perhaps to its relative steepness and the influence of conifers in the immediate vicinity (small conifers) and general vicinity (large conifers).

Integrated Ram hardness was variable across the beach ridge sampled by transect 7 (Fig. 18). Integrated Ram hardness was relatively low in the vicinity of the apex; however, the values recorded at the apex (station 11) were generally higher than those from adjacent stations (stations 9, 10 and 12, 13). The relatively low values recorded at stations 9 and 10 may have related to the relative steepness of these stations. The stations located closest to Hudson Bay (low end of transect) had values considerably higher than those from the other end of the transect at the third sampling period.

Integrated Ram hardness within the fen community (Fig. 19) did not exhibit the marked variability which was apparent for the beach ridges. This variable did not differ substantially between sampling periods 1 and 2. Integrated Ram hardness was considerably higher and more variable for the majority of stations at sampling period 3.

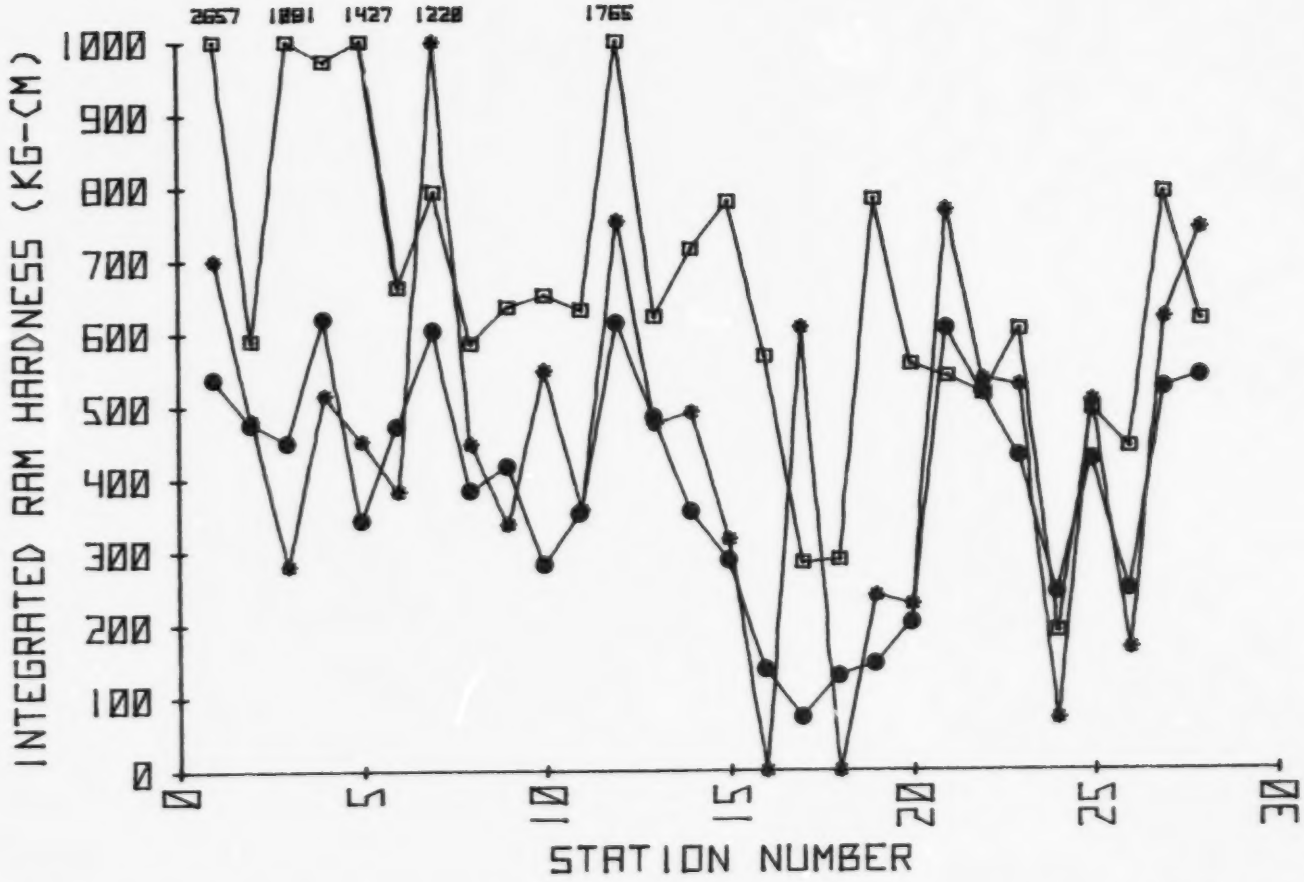

Fig. 16. Integrated Ram hardness on 30 January (✱), 26 February (●), and 28 March (⊡) for transect 4.

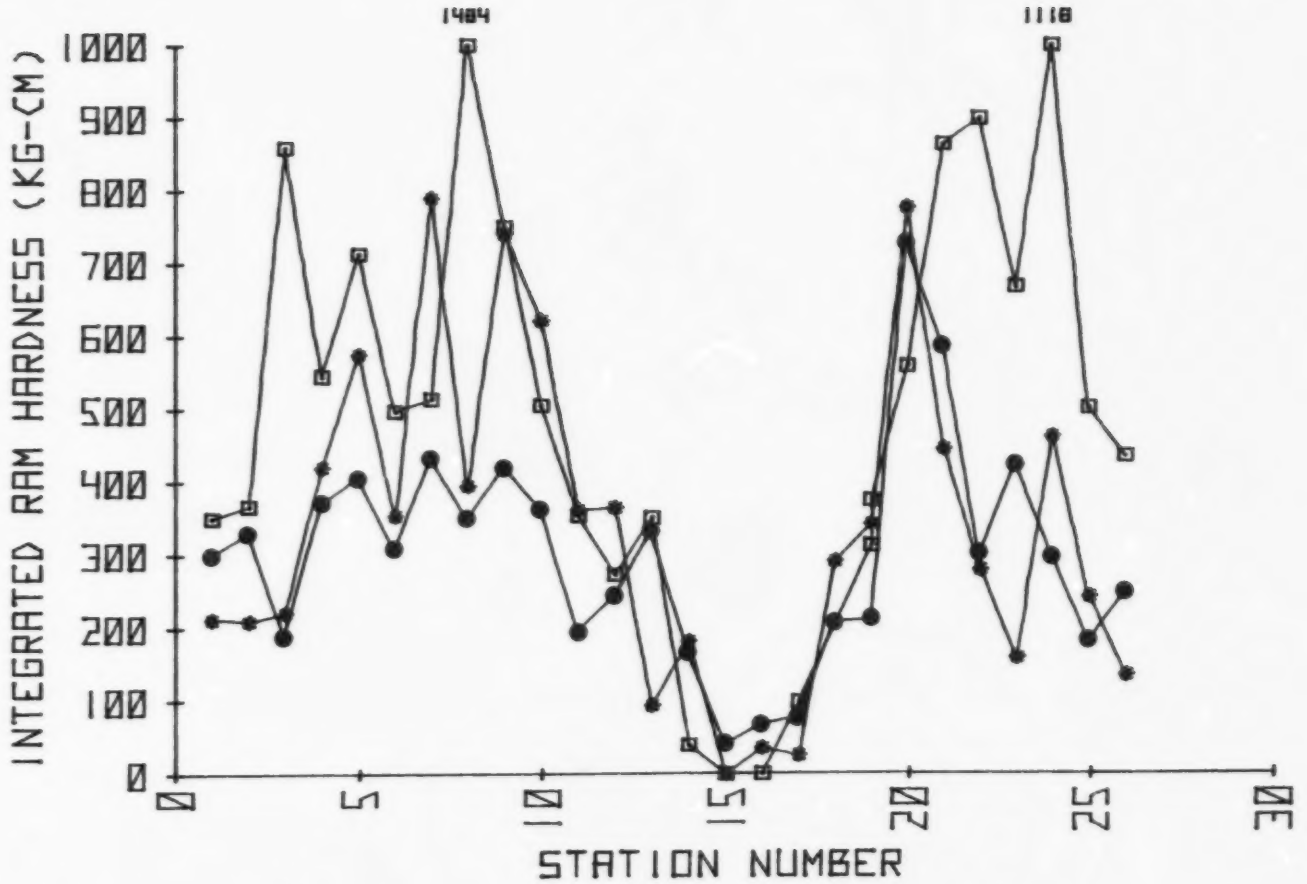

Fig. 17. Integrated Ram hardness on 30 January (✱), 26 February (●), and 29 March (⊡) for transect 5.

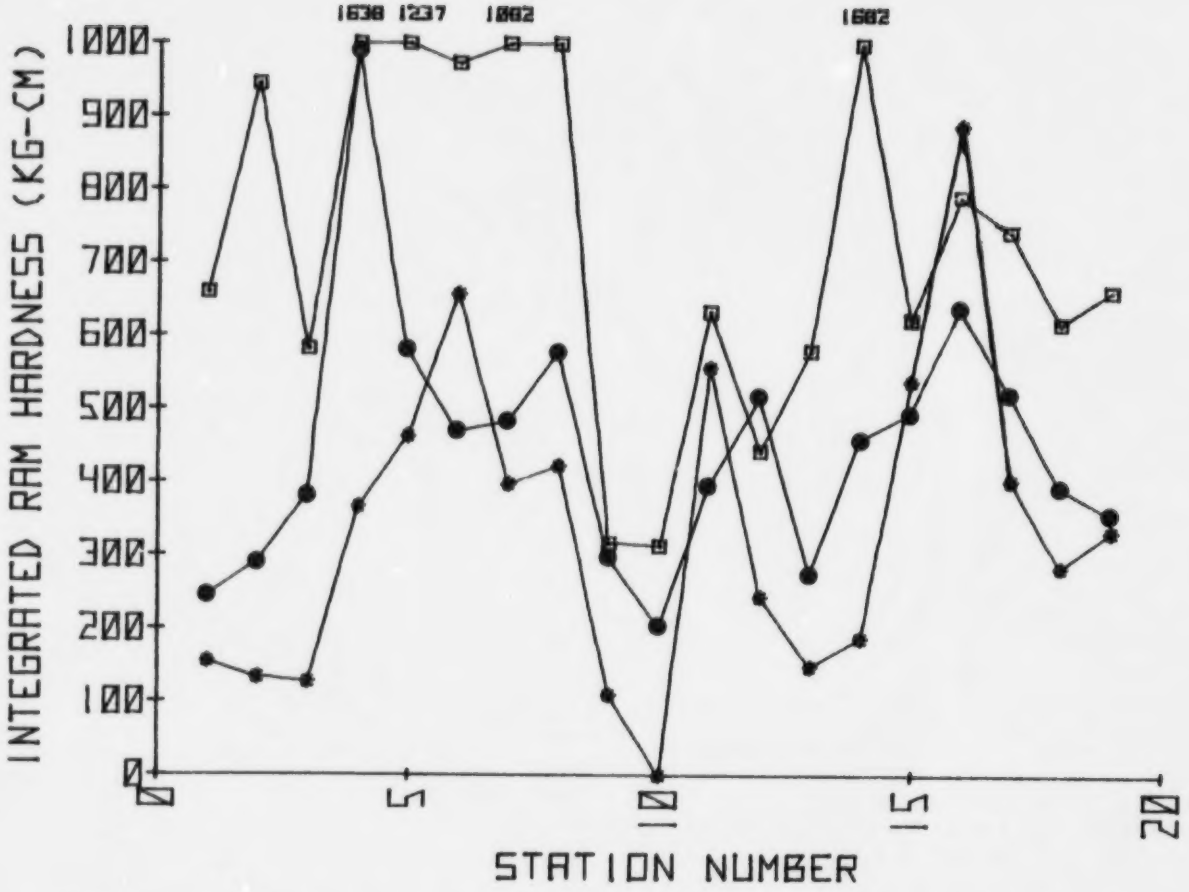

Fig. 18. Integrated Ram hardness on 1 February (✱), 25 February (●), and 28 March (⊡) for transect 7.

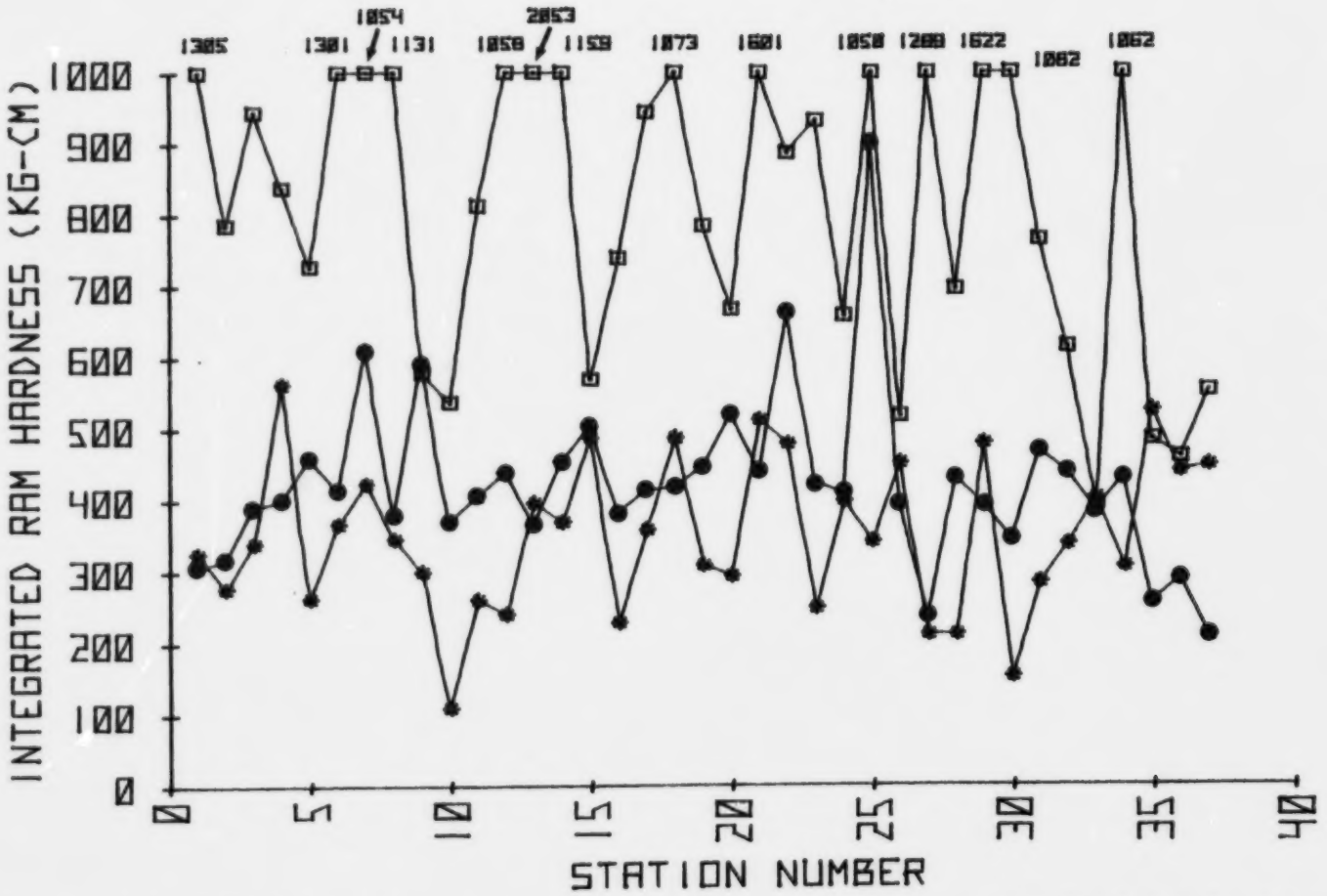

Fig. 19. Integrated Ram hardness on 31 January (✱), 25 February (●), and 28 March (⊡) for transect 6.

Temporal and community variation in integrated Ram hardness

Mean integrated Ram hardness within the fen community increased ($P < 0.01$) from the first to the second sampling period (Table 5) but was not different between these periods for the ridge and modified communities. An increase in mean integrated Ram hardness occurred from sampling period 2 to sampling period 3 within the ridge ($P < 0.005$), fen ($P < 0.005$), and modified communities ($P < 0.005$).

The mean integrated Ram hardness for the modified community was greater than that for the ridge ($P < 0.01$) and fen communities ($P < 0.005$) for the first sampling period. Mean integrated Ram hardness was less within the ridge community as compared to the other 2 communities for the later 2 sampling periods ($P < 0.002$). The variance (and standard deviation) of integrated Ram hardness was greater for the third sampling period as compared to the first sampling period for all 3 communities.

Table 5. Mean integrated Ram (modified Rammsonde) hardness (kg·cm) for 3 vegetation communities sampled from 29 January-29 March 1987.

Sampling period	Ridge (n=72)		Fen (n=37)		Modified (n=75)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
29 Jan-1 Feb	302[a,c]	237[a]	351[c]	109[d,e]	437[d]	215[a]
25 Feb-26 Feb	289[a]	152[b]	426[d]	123[b,d]	419[d]	140[b,e]
28 Mar-29 Mar	571[b]	338[c]	912[e]	360[c]	889[e]	439[f]

[a,b,c,d,e,f]Mean integrated Ram hardness and standard deviations with the same letters are not significantly different (z test, F test, $P > 0.05$).

Integrated Ram hardness within the ridge and modified communities

The mean integrated Ram hardness at the stations within the ridge community increased for some transects and decreased for others from the first sampling period to the second (Table 6). Mean integrated Ram hardness at these stations was much greater at the third sampling period for all transects with the exception of transect 5 which had a slightly lower mean.

Table 6. Means and standard deviations for integrated Ram (modified Rammsonde) hardness (kg·cm) within the ridge and modified communities and the combination of these 2 communities for transects which sampled beach ridges.

Sampling period	Transect number	Community: Ridge $\bar{x}$	Ridge SD	Modified $\bar{x}$	Modified SD	Ridge and Modified $\bar{x}$	Ridge and Modified SD
29 Jan-1 Feb	1	404[a]	238	392	204	401	227
	2	159[b,c]	150	420	212	345	228
	3	172[c,d]	190	396	207	270	222
	4	364[a,d]	250	550[a]	243	457	260
	5	235	247	390[b]	198	336	224
	7	226	180	460	219	358	230
25-26 Feb	1	314	156	456[a,b]	150	349	164
	2	275	89	387[b,c]	123	354	124
	3	205[a]	84	396	99	288	131
	4	310	169	470[a,d]	106	390	161
	5	231	209	336[c]	103	300	153
	7	358[b]	109	557[a,d]	183	470	182
28-29 Mar	1	705[a]	297	887	479	749	350
	2	718[a,c]	406	952[a]	426	885	427
	3	440[b,c]	309	979[a]	411	676	441
	4	541[a,c]	192	979	601	766	491
	5	220[b]	195	672[b]	303	515	345
	7	662[a,c]	472	950[a]	345	824	418

[a,b,c,d]For a sampling period in a community, integrated Ram hardness means with different letters are significantly different (t test, $P \leq 0.05$).

For stations within the modified community, mean integrated Ram hardness increased for some and decreased for other transects from the first to the second sampling period. The means recorded from these stations at the third sampling period were much greater than those recorded at the second sampling period.

Within the ridge community, integrated Ram hardness at sampling period 1 was greater for transect 1 than for transects 2 ($P < 0.02$) or 3 (P

< 0.02). Integrated Ram hardness for transect 2 was also lower than that for transect 4. The only difference between transects at the second sampling period was the mean integrated Ram hardness for transect 7 which was greater than that for transect 3 ($P < 0.01$). At sampling period 3, integrated Ram hardness was greater for transect 1 than transect 3 and lower for transect 5 than transects 1 ($P < 0.01$), 2 ($P < 0.01$), 4 ($P < 0.01$), or 7.

The mean integrated Ram hardness within the modified community was consistently low for the stations at the ridge sampled by transect 5. Integrated Ram hardness for transect 5 was lower than that for transect 4 at the first sampling period. At the second sampling period, integrated Ram hardness was lower for transect 5 than for transects 1, 4 ($P < 0.01$), or 7 ($P < 0.01$). Integrated Ram hardness was lower for transect 5 than for transects 2, 3, or 7 at the third sampling period. Transect 2 was the only other transect with integrated Ram hardness significantly different ($P \leq 0.05$) from that of other transects. Integrated Ram hardness for transect 2 was less than that for transects 4 or 7 ($P < 0.01$) at the second sampling period.

Snow measurements - potential thresholds

A substantial proportion of stations located within the ridge community had snow depths ≤20 cm for all 3 sampling periods (Table 7). Within the modified community, 24% of the stations had a snow depth ≤20 cm for the first sampling period but few stations had a snow depth ≤20 cm for other sampling periods and for all sampling periods within the fen community.

The majority of stations had a depth ≤30 cm for the first sampling period within the ridge, fen, and modified communities. A large proportion of stations continued to have a depth ≤30 cm within the ridge community for the other 2 sampling periods. The proportion of stations with a depth ≤30 cm decreased considerably within the fen and modified communities following the first sampling period.

The proportion of stations with an integrated Ram hardness ≤400 kg·cm increased from the first sampling period to the second sampling period within the ridge community, decreased within the fen community, and remained

Table 7. Percentage of stations with snow depth (cm) and integrated Ram (modified Rammsonde) hardness (kg·cm) below potential thresholds for muskoxen.

Plant community	n	Sampling period	≤20 cm	≤30 cm	≤400 kg·cm	≤30 cm and 400 kg·cm
Ridge	72	29 Jan-1 Feb	88	97	67	67
		25 Feb-26 Feb	49	83	79	72
		28 Mar-29 Mar	53	78	31	31
Fen	37	29 Jan-1 Feb	8	76	68	51
		25 Feb-26 Feb	0	27	41	14
		28 Mar-29 Mar	0	16	3	0
Modified	75	29 Jan-1 Feb	24	69	52	48
		25 Feb-26 Feb	4	16	53	15
		28 Mar-29 Mar	3	13	5	4

constant within the modified community. Few stations had an integrated Ram hardness ≤400 kg·cm within the fen and modified communities for the third sampling period. The proportion decreased to 31% within the ridge community for the third sampling period.

The proportion of stations with snow depth ≤30 cm and integrated Ram hardness ≤400 kg·cm was generally similar to the proportion for integrated Ram hardness alone. The greatest exceptions occurred for sampling period 2 within the fen and modified communities.

Snow characteristics within the fen community adjacent to beach ridges

Snow depth and integrated Ram hardness data were available from the fen community for 3 transects which sampled beach ridges (Table 8). Six measurements were collected on the side of the ridge closest to Hudson Bay and 7 measurements were collected on the opposite side. One station was located within a depression where snow depth was considerably greater than mean values (36, 44, and 55 cm for sampling periods 1, 2, and 3 respectively). Snow depth had increased by sampling period 2 ($P < 0.01$) but did not change from periods 2 to 3. Integrated Ram hardness was not different between periods 1 and 2 but had increased by sampling period 3 (P

< 0.01).

Snow depths within the fen community sampled by transect 6 (Table 3) were not different from snow depths within this community from the transects which sampled beach ridges for periods 1 ($t = -0.20$, $P > 0.20$), 2 ($t = -1.66$, $P > 0.10$), or 3 ($t = -1.56$, $P > 0.10$). The mean integrated Ram hardness was not different between these sources of data for periods 1 ($t = 0.46$, $P > 0.20$), 2 ($t = 0.31$, $P > 0.20$), or 3 ($t = 0.10$, $P > 0.20$).

Table 8. Means and standard deviations for snow depth (cm) and integrated Ram (modified Rammsonde) hardness (kg·cm) for stations located within the fen community from transects across beach ridges (n=13). Data comes from transect 2 (n=3), transect 3 (n=7), and transect 7 (n=3).

Sampling period	Snow depth		Integrated Ram hardness	
	$\bar{x}$	SD	$\bar{x}$	SD
29 Jan-1 Feb	27.2	5.3	332[a]	174
25-26 Feb	38.6[a]	8.2	412[a]	182
28-29 Mar	44.8[a]	12.5	899	462

[a]Means with the same letter are not significantly different (t-test, $P > 0.05$).

Snow depth and physical characteristics of the beach ridge

The influence of height below the apex on snow depth was investigated by application of linear ($y = B_0 + B_1x$), logarithmic ($y = B_0 + B_1 \ln x$), power ($\ln y = \ln B_0 + B_1 \ln x$), and exponential ($\ln y = \ln B_0 + B_1x$) models to the data. Those values of snow depth which were <1 (i.e., 0 and 0.5) were changed to 1 for application of those models which required the natural logarithm of the variable. The data fit the power model best for all 3 sampling periods (Table 9). The coefficient of determination was relatively high for the power model for the second and third sampling periods in particular. The best fit to the power model indicates that a curvilinear relationship exists between snow depth and height below apex with snow depth increasing at a slower rate farther below the apex than near

the apex.

The influence of additional physical characteristics on snow depth was investigated via multiple linear regression (backwards elimination) analysis. The natural logarithm of snow depth and height below the apex were used in the analysis to reflect the relationship between the 2 variables. The additional independent variables examined were distance from the apex and 2 variables which were designed to describe relief characteristics. The distance from the apex represents the distance along the transect (beach ridge) and is therefore not an exact measure of distance in a level plane from the apex.

Table 9. Coefficients of determination (r^2) for snow depth (cm) and integrated Ram (modified Rammsonde) hardness (kg·cm) versus height below apex (cm) for linear, logarithmic, power, and exponential models.

Dependent variable	Sampling period	Model			
		Linear	Logarithmic	Power	Exponential
Snow depth	1	0.34	0.34	0.35	0.31
	2	0.37	0.41	0.52	0.39
	3	0.35	0.40	0.51	0.36
Integrated Ram hardness	1	0.08	0.10	0.25	0.14
	2	0.13	0.17	0.28	0.17
	3	0.09	0.13	0.22	0.11

The two variables used to describe relief characteristics relate to the relative vertical position of the station located immediately ahead (toward the apex) and behind (toward the base) a given station. These values are <u>almost</u> equivalent to estimates of slope for the purpose of regression analysis. The values would relate directly to slope because the distance between stations is almost equivalent and constant; however, the values would not be a perfect linear index to slope because true distance between stations in the horizontal plane is slightly variable (as a function of snow conditions when the transects were located and the differences in

elevation between stations). The height below apex for the station ahead and the station behind were subtracted from the height below apex for a given station to result in the variables STAH and STBH respectively. The variable STAH was generally positive (i.e., located above the intermediate station) while the variable STBH was generally negative (i.e., located below the intermediate station); the magnitude of the numbers is indicative of how different the adjacent stations are (i.e., the degree of slope). An apex located on either side of the beach ridge would have negative values for both STAH and STBH (because the apex is located above both adjacent stations); a depression would have positive values for both STAH and STBH. The apex of each beach ridge had the same numbers generated for STAH and STBH because values for these variables were calculated for each side of a ridge (until and including when the apex was reached). One of these values was randomly assigned to STAH and the remaining value assigned to STBH.

The treatment of the data in this manner resulted in a decrease in the sample size. Those stations without 2 adjacent stations (eg., stations at the ends of transects and stations adjacent to ponds) were not included in the analysis because values for STAH and STBH could not be calculated. Those stations located in ponds and those stations from transect 6 (the transect located in the fen habitat) were not included in the analysis. This treatment resulted in a data set of 146 observations from 6 different transects. The influence of these variables on snow depth was evaluated for each sampling period separately because snow depth increased with sampling period.

The ln of snow depth was influenced by ln of height below apex and STBH at all sampling periods and STAH at sampling period 2 (Table 10). STAH and ln of snow depth were positively but not significantly related at sampling periods 1 ($t = 0.94$, $df = 142$, $P > 0.30$) and 3 ($t = 1.65$, $df = 142$, $P = 0.10$).

The relationship between ln of snow depth and ln of height below apex is presented for the 3 sampling periods in Table 10. These relationships (ln snow depth = $B_0 + B_1$ ln height below apex) are equivalent to snow depth = antilogB_0 (height below apex)^{B_1} (eg., for sampling period 1, snow depth = 2.88 (height below apex)$^{0.417}$. The additional significant variables increased the coefficient of determination from 0.35 to 0.42, 0.52

Table 10. Regression statistics for the natural logarithm of snow depth (cm) as related to several independent variables.

Sampling period	Regression model[a]	F	df	R^2/r^2	P
1	SNOW = 1.34 + 0.392 HT[b]* + 0.018 STBH*	35.09	2,143	0.42	<0.001
	SNOW = 1.058 + 0.417 HT*	78.16	1,144	0.35	<0.001
2	SNOW = 2.308 + 0.259 HT* + 0.013 STBH* + 0.008 STAH*	75.75	3,142	0.62	<0.001
	SNOW = 2.053 + 0.309 HT*	153.63	1,144	0.52	<0.001
3	SNOW = 1.654 + 0.435 HT* + 0.013 STBH*	87.72	2,143	0.55	<0.001
	SNOW = 1.459 + 0.452 HT*	149.72	1,144	0.51	<0.001

[a]SNOW represents ln of snow depth, HT represents ln of height below apex, STBH and STAH relate to relative vertical position of adjacent stations and are defined in text.
[b]Regression coefficient significant (* $P \leq 0.001$), t test, df = 142 or 143.

to 0.62, and 0.51 to 0.55 for the first, second, and third sampling periods respectively. The ln of snow depth was not related to distance from the apex for any sampling period, likely the result of a strong relationship between distance from apex and height below apex. The ln of snow depth was positively related to STBH for all 3 sampling periods. This relationship is likely a reflection of the ability of this variable to indicate depressions. A high positive value of STBH results in an increased snow depth and is indicative that the station behind was higher in elevation than the station being examined. A depression would be the likely result because the station ahead (STAH) was generally located above the station in question. The significant and positive influence of STAH for sampling period 2 and the positive association (although not significant) for sampling periods 1 and 3 further support these statements because positive STBH and STAH are indicative of a depression and negative values indicative of an apex.

Integrated Ram hardness and physical characteristics of the beach ridge

The influence of height below apex on integrated Ram hardness was

investigated by application of the linear, logarithmic, power, and exponential models to the data. Those values of integrated Ram hardness which were <1 were changed to 1 for the application of those models which required the natural logarithm of the variable. The data fit the power model best for all 3 sampling periods (Table 9). The coefficient of determination (r^2) was relatively high for the power model for all 3 sampling periods, indicative of a curvilinear relationship similar in form to that between snow depth and height below apex.

The relationship between ln of integrated Ram hardness and the four physical characteristics was examined via multiple linear regression analysis. The ln of height below apex was used as one of the independent variables. Although integrated Ram hardness did not change from sampling period 1 to 2, the physical structure of the snow had likely changed (as snow depth had increased substantially); therefore, the analysis was conducted separately for each sampling period.

The ln of integrated Ram hardness was related to ln of height below apex and STBH at all sampling periods and STAH at sampling periods 2 and 3 (Table 11). STAH and ln of integrated Ram hardness were positively but not significantly related at sampling period 1 ($t = 1.46$, $df = 142$, $P > 0.10$).

The relationships between ln of integrated Ram hardness and ln of height below apex (Table 11) can be adjusted to the form $y = \text{antilog}B_0\ x^{B}1$, as outlined previously for snow depth. The additional significant variables increased the coefficient of determination from 0.25 to 0.28, 0.28 to 0.35, and 0.22 to 0.26 for the first, second, and third sampling periods respectively. The increases, while statistically significant, do not substantially increase the relatively weak predictive capability of the model which uses ln of height below apex as the sole independent variable. The distance from the apex did not significantly influence ln of integrated Ram hardness, likely the result of a strong relationship between distance from apex and height below apex. The utility of STBH and STAH as indicators of the influence of depression and apices was indicated by their significant relationship (with the exception of STAH at the first sampling period) and positive association with ln of integrated Ram hardness. The analysis indicates that depressions acted to elevate integrated Ram hardness while

apices acted to decrease integrated Ram hardness.

Table 11. Regression statistics for the natural logarithm of integrated Ram (modified Rammsonde) hardness (kg·cm) as related to several independent variables.

Sampling period	Regression model[a]	F	df	R^2/r^2	P
1	RAM = 3.831 + 0.470 HT[b]*** + 0.018 STBH**	28.25	2,143	0.28	<0.001
	RAM = 3.552 + 0.494 HT***	47.62	1,144	0.25	<0.001
2	RAM = 5.052 + 0.179 HT*** + 0.009 STBH** + 0.008 STAH**	25.10	3,142	0.35	<0.001
	RAM = 4.853 + 0.227 HT***	56.08	1,144	0.28	<0.001
3	RAM = 5.048 + 0.335 HT*** + 0.014 STBH* + 0.014 STAH*	16.81	3,142	0.26	<0.001
	RAM = 4.741 + 0.408 HT***	41.18	1,144	0.22	<0.001

[a]RAM represents ln of integrated Ram hardness, HT represents ln of height below apex, STBH and STAH relate to relative vertical position of adjacent stations and are defined in text.
[b]Regression coefficient significant (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$), t test, df = 142 or 143.

Influence of aspect and other variables on snow depth and integrated Ram hardness

The data set was separated into stations located on the Hudson Bay side of the apex and stations located on the opposite side. The influence of aspect (i.e., side of the beach ridge) was investigated by examining the increase in predictive capability when the complete data set (i.e., stations from both sides) was separated to reflect aspect. The apices were deleted from the analysis because an apex could actually be located on either side of a beach ridge (due to the 5 m sampling interval).

For the complete data set, the relationship between snow depth or integrated Ram hardness and height below apex best fit the power model at all sampling periods. Multiple regression analysis resulted in models identical to those found for the data set which included apices (Tables 10,

11) with the exception of integrated Ram hardness at sampling period 3 (ln of height below apex was the only significant variable). These models were applied to the separate data sets and the SSE for the complete data set (1 equation) and separate data sets (addition of SSE from the 2 equations) were compared (Table 12). This procedure is equivalent to treatment of aspect as a dummy variable (the analytical package did not have this capability).

For all models, the residual sum of squares decreased when the complete data set was separated to reflect differences in aspect. The significance of the increase in the coefficient of determination was tested with a test of coincidence (generally used with dummy variables) with aspect treated as if it had been a dummy variable. Aspect significantly influenced 3 of the regression models (snow depth at sampling periods 2 and 3 and integrated Ram hardness at sampling period 1) when this relatively powerful test was applied.

Table 12. Importance of aspect to the prediction of snow depth (natural logarithm cm) and integrated Ram (modified Rammsonde) hardness (natural logarithm kg·cm).

Dependent variable	Sampling period	One equation			Two equations			
		SSE	SSY	R^2	SSE	R^2	F	p[a]
Snow depth	1	56.720	94.887	0.402	55.661	0.413	0.85	>0.25
	2	14.586	28.722	0.492	13.361	0.535	3.03	<0.025
	3	34.592	62.865	0.450	32.604	0.481	2.72	<0.05
Integrated Ram hardness	1	127.359	183.098	0.304	120.091	0.344	2.70	<0.05
	2	22.490	29.378	0.234	21.948	0.253	0.82	>0.25
	3	77.384	86.345	0.104	76.393	0.115	0.88	>0.25

[a]Degrees of freedom were 2,136 (HT), 3,134 (HT, STBH), or 4,132 (HT, STBH, STAH) dependent upon model; test of coincidence for aspect as a dummy variable with increase in SSR divided by 2, 3, or 4 prior to division by the MSR to yield an F statistic (see Kleinbaum and Kupper 1978, p. 194).

The relationship between integrated Ram hardness and snow depth

Integrated Ram hardness was regressed against snow depth for each

sampling period for the beach ridge (all plant communities) and the transect (6) located exclusively within the fen community. For the beach ridge, the data best fit the power model at all sampling periods (Table 13). Integrated Ram hardness was positively related to snow depth at sampling periods 1 ($F = 219.67$, $df = 1,158$, $P < 0.001$), 2 ($F = 215.55$, $df = 1,158$, $P < 0.001$), and 3 ($F = 257.78$, $df = 1,158$, $P < 0.001$) with r^2 values between 0.58 and 0.62. Integrated Ram hardness increased at a faster rate in deep snow as compared to shallow snow for sampling periods 1 and 3. In contrast, integrated Ram hardness increased at a slower rate in relatively deep snow for sampling period 2.

Table 13. Coefficients of determination (r^2) for integrated Ram (modified Rammsonde) hardness (kg·cm) versus snow depth (cm) for the linear, logarithmic, power, and exponential models.

Location	Sampling period	Model			
		Linear	Logarithmic	Power	Exponential
Beach ridge	1	0.46	0.39	0.58	0.39
	2	0.51	0.45	0.58	0.52
	3	0.28	0.31	0.62	0.28
Transect 6	1	0.02	0.04	0.10	0.06
	2	0.31	0.26	0.19	0.22
	3	0.16	0.14	0.13	0.14

For the transect located entirely within the fen community, integrated Ram hardness and snow depth were not related at sampling period 1 although the data best fit the power model ($F = 3.71$, $df = 1,35$, $P < 0.10$). The data best fit the linear model for sampling periods 2 and 3 although the r^2 values for sampling period 3 were low and almost the same for all models. Integrated Ram hardness was positively related to snow depth for sampling periods 2 ($F = 15.47$, $df = 1,35$, $P < 0.001$) and 3 ($F = 6.49$, $df = 1,35$, $P < 0.025$).

The models of best fit are detailed in Table 14 for the beach ridge at all sampling periods and the fen community (transect 6) for

sampling periods 2 and 3. The model for sampling period 1 was not included because it was not statistically significant.

The slope of the linear relationship between integrated Ram hardness and snow depth was not different between sampling periods 2 and 3 ($F = 0.90$, $df = 1,70$, $P > 0.25$) for the fen community. The intercepts were also not different ($z = 0.52$, $P = 0.60$) for the regression lines for these 2 periods. These analyses indicate that the null hypothesis of coincident lines cannot be rejected and, therefore, it cannot be stated that the relationship between integrated Ram hardness and snow depth differed between sampling periods 2 and 3.

Table 14. Linear and power models for the relationship between integrated Ram (modified Rammsonde) hardness (kg·cm) and snow depth (cm) for the beach ridges and the fen community (transect 6).

Location	Sampling period	Regression model	F	df	P
Beach ridges	1	$RAM = 12.876\ SNOW^{1.083}$	219.67	1,158	<0.001
	2	$RAM = 25.842\ SNOW^{0.764}$	215.55	1,158	<0.001
	3	$RAM = 17.262\ SNOW^{1.075}$	257.78	1,158	<0.001
Fen (transect 6)	2	$RAM = 9.56\ SNOW + 94.59$	15.47	1,35	<0.001
	3	$RAM = 16.78\ SNOW + 241.27$	6.49	1,35	<0.025

[a]RAM represents integrated Ram hardness; SNOW represents snow depth.

The relationship between integrated Ram hardness and snow depth across the beach ridges was compared for all 3 sampling periods. The slopes and intercepts were compared for the linear regressions of the ln of integrated Ram hardness versus ln of snow depth. The slope of the relationship at sampling period 2 (0.764) was different from that at sampling period 1 ($F = 8.83$, $df = 1,316$, $P < 0.005$) and sampling period 3 ($F = 10.70$, $df = 1,316$, $P < 0.005$). The slope of the relationship at sampling period 1 (1.083) did not differ ($F = 0.01$, $df = 1,316$, $P > 0.25$) from that at sampling 3 (1.075). The intercept of the relationship at sampling period 1 was different from the intercept at sampling period 2

($z = -2.56$, $P = 0.01$). The intercept of the relationship at sampling period 3 was not different from the intercept at sampling period 1 ($z = 0.95$, $P = 0.34$) or sampling period 2 ($z = -1.42$, $P = 0.16$).

A multiple regression analysis was conducted to determine if several independent variables additional to the ln of snow depth influenced integrated Ram hardness (ln) across the beach ridges. The additional independent variables were height below apex, distance from apex, and the two relief variables (STAH and STBH). None of the additional independent variables were significantly ($P \leq 0.05$) related to ln of integrated Ram hardness at sampling periods 1 and 2. Height below apex was the only additional independent variable which related to ln of integrated Ram hardness at sampling period 3 ($t = -3.65$, $df = 143$, $P < 0.001$). The negative coefficient for height below apex (-0.005) indicates that integrated Ram hardness decreased with increasing height below the apex. The magnitude of this coefficient is such that it would have a minor influence on integrated Ram hardness as compared to ln of snow depth (coefficient of 1.264). The coefficient of determination increased from 0.62 to 0.66 with the addition of height below apex to the regression model.

The influence of aspect on the relationship between integrated Ram hardness and snow depth (snow depth and height below aspect at the third sampling period) was investigated with the same method and data set used previously to examine aspect. Aspect did not influence the relationship between ln of integrated Ram hardness and ln of snow depth at sampling period 1 ($F = 0.24$, $df = 2,136$, $P > 0.25$) but was found to have an effect at sampling periods 2 ($F = 4.04$, $df = 2,136$, $P < 0.025$) and 3 ($F = 2.84$, $df = 3,134$, $P < 0.05$). The coefficient of determination increased from 0.50 to 0.52 at sampling period 2 and from 0.56 to 0.59 at sampling period 3 with the addition of aspect to the regression model. The 2 regression equations at sampling period 2 (for the 2 sides of the beach ridges) would yield similar estimates of integrated Ram hardness at a snow depth of 30 cm. Estimates of integrated Ram hardness were greater for snow depth <30 cm for the equation developed from stations on the Hudson Bay side of the apices.

DISCUSSION

Vegetational characteristics

The variability between transects in the proportion of each plant community in the sample relates in part to not extending each transect to the fen community on both sides of the apex and/or a stable elevation. The ability to compare community composition is compromised to an unknown degree as a result.

The dominance of the ridge community on transect 1 was likely due to the relatively great relief and incomplete sampling of this two-ridge complex. The relative composition of plant communities was also likely related to depressions within a ridge and the influence of an adjacent ridge for two-ridge complexes. The determination of community boundaries within this transitional habitat may not always have been exact thereby influencing proportions (eg., Should a quadrat covered 98% by a fen community and 2% by a hummock with additional species be classified as a fen community or a modified community?). The relative composition of plant communities was also likely related to differences in parent material of the ridges and the period available for soil and plant communities to develop (i.e., the length of time which the parent material had been out of water; the vegetation of transect 4 may reflect this factor). Rewcastle (1983) provided a review of the influence of time, and other important factors, on plant community development on beach ridges.

Snow depth

Snow depth varied within the ridge and modified communities from transect to transect. The indicated differences between one transect and another should be treated cautiously. The probability that a true hypothesis will be rejected increases as more null hypotheses are tested (Kleinbaum and Kupper 1978). It would be expected that approximately 2 incorrect rejections (i.e., incorrectly inferring that snow depth was different for 2 transects) would result from the 45 comparisons (3 sampling periods) made for each community (at $P \leq 0.05$). One significant difference was found within the ridge community and 10 within the modified community. This suggests that little, if any, variation in snow depth existed between

transects for the ridge community but that snow depth did differ between transects within the modified community.

The generally deeper snow found at the ridge sampled by transect 4 may reflect structural differences of this ridge. This transect sampled the modified community primarily on the side of the ridge closest to Hudson Bay (only 1 station was located on the opposite side of the ridge). Several depressions were located within the community and the transect appeared to have sampled the ridge adequately to the point where the ridge had essentially levelled out (both of these factors may have resulted in deeper snow accumulation). These structural differences contrast with the other ridges with the exception of the ridge sampled by transect 3 (although the ridge sampled by transect 3 was much steeper). The ridge sampled by transect 4 was also the lowest (above base) of all the ridges with the exception of the ridge sampled by transect 7. The greater snow depths apparent for this ridge may also relate to the possible greater age of this ridge (located further inland and possibly at a higher elevation). It is possible that the modified community has been able to develop in the peripheral portion of the ridge because peat has accumulated over a greater length of time.

The beach ridge sampled by transect 7 was similar in structure to that sampled by transect 4 in terms of height above base and relative flatness at the peripheral stations. Although no stations were located in obvious depressions, 2 stations were located adjacent to a depression and snow accumulation could have been enhanced as a result. Structurally, this ridge differed considerably from the ridge sampled by transect 2. The ridge sampled by transect 3 was similar in terms of height above base and the potential influence of depressions but differed in that several stations within the modified community were found at relatively steep locations where snow depth would be expected to be low.

Snow depth at stations within the ridge community increased from the second to third sampling period for 2 transects but decreased for 4 transects. The increase in snow depth occurred for 2 transects located in the northern portion of the study area which suggests that geographic variation (eg., differences in snowfall and/or wind effects on the snow) may have been important. Over these same periods, snow depth increased at

stations within the modified community for all transects excepting one from the southern portion of the study area. The lack of agreement between these communities suggests that factors other than location per se were responsible for differences in snow depth.

As snow depth is related to height below apex and several additional structural characteristics, it is very likely that variation between transects related considerably from structural differences among ridges. The observed variation between transects may also have related to differences in community classification (in the zone where species composition changes and/or weakness in the classification system) or community development (due to differences in age and/or edaphic conditions). The observed results may have occurred, in part, because sampling did not extend to the fen community for a number of transects and was therefore incomplete.

Integrated Ram hardness

Integrated Ram hardness was highly variable with low values and high values recorded near both apices and ends of beach ridges. Within the ridge and modified communities, integrated Ram hardness at the stations increased for some transects and decreased for others from the first to second sampling periods. The resistance of the snow column to penetration was substantially greater at sampling period 3 for all transects and communities with the exception of the ridge community of transect 5.

Integrated Ram hardness was found to vary within the ridge and modified communities among transects. The indicated differences between one transect and another should be treated with caution due to the large number of comparisons made (45 per plant community). There were 9 significant ($P < 0.05$) differences between transects for each of the ridge and modified communities which suggests that integrated Ram hardness really did vary between transects within each of these plant communities.

Integrated Ram hardness is related to snow depth, hence, the variation in this measure reflects differences in snow depth between transects and sampling periods. It is also apparent that integrated Ram hardness is a function of more than snow depth (eg., integrated Ram hardness was considerably higher for the majority of transects at sampling

period 3 with relatively minor changes in snow depth from sampling period 2, integrated Ram hardness was greater for the ridge community than the modified community despite a considerably lower snow depth for transect 1 at sampling period 1). Additionally, the relationship between integrated Ram hardness and snow depth is modified somewhat by the influence of structural characteristics of the ridges. The snow within the ridge community may also be influenced by wind to a different extent than snow within the modified community. There was relatively little difference in integrated Ram hardness for transects 2 and 4 despite a substantial difference in snow depth at sampling period 2. It is likely that the very attributes (structural) which allowed the accumulation of snow also resulted in snow of relatively low density for one of these transects (and subsequent small differences in integrated Ram hardness). The relatively steep structure of the ridges sampled by transects 3 and 5 may have had an influence on the observed low Ram hardness values for these transects.

The influence of solar insolation and temperature on the snow column and the surface of the snow column (i.e., the formation of a snow crust) is an important factor which would influence integrated Ram hardness irrespective of depth. The relatively high values recorded for most transects at sampling period 3 may reflect the influence of temperature and insolation because a crust was apparent at the majority of stations sampled (S. Ransom, Manitoba Wildlife Branch, pers. commun.). The relatively low values of integrated Ram hardness at transect 5 for sampling period 3 were noted by S. Ransom (Manitoba Wildlife Branch, pers. commun.) while collecting these measurements. These low values may result from the relative protection afforded this ridge by small (<5 m) scattered conifers adjacent to the ridge and stands of large (>10 m) conifers located west and north within 1 km of the ridge. Variation in integrated Ram hardness may also have related to weakness in the community classification system and/or the influence of age and edaphic conditions on community development. The role of incomplete sampling likely had an important influence on comparisons between transects (particularly relative to the modified community) and should be recognized.

The integrated Ram hardness values within the modified community of transect 5 were generally low as was found for the ridge community of

this transect. The similar results for both communities of this transect suggests that factors other than structure of the ridge were responsible for the observed differences. Geographic location (differences in snowfall or wind), additional characteristics detailed in Table 1, or the presence of conifers may have influenced integrated Ram hardness.

Snow characteristics within the fen community adjacent to beach ridges

The fen community was weakly sampled by the transects across the beach ridges. Snow depth increased in this community from sampling period 1 to 2 but had not increased by sampling period 3. Integrated Ram hardness increased from sampling period 2 to 3. Snow depth and integrated Ram hardness did not differ between these stations and the fen community sampled by transect 6 at any of the sampling periods. The small sample size for these stations (13) may have been critical to the inability to detect a difference if one existed.

Snow depth and physical characteristics of the beach ridge

Snow was relatively shallow in the vicinity of the apex on apices of all beach ridges. The modifying influence of the ridges on wind and subsequent snow deposition led to the occurrence of relatively deep snow near the base of all ridges. A curvilinear relationship existed such that snow depth increased at a slower rate at greater heights below the apex. Snow was relatively deep in depressions and shallow on apices below the major apex. Snow depth may also have been influenced by the presence of a second major apex (two-ridge complexes), orientation of a ridge, and variation in the structure of the underlying vegetation (eg., variable provision of support). It appeared that slope was expressed marginally by STAH and STBH as compared to their ability to express the influence of depressions and apices on snow depth. The attempt to simultaneously model the influence of slope and depressions/apices with these variables may have poorly reflected the influence of these factors on snow depth. An analysis which treated depressions and apices separately (eg., as dummy variables and with more data) from slope (slope of stations located at neither depressions or apices) or constructed a meaningful interaction term quite possibly would have led to a better model and predicative capability.

Integrated Ram hardness and physical characteristics of the beach ridge

Integrated Ram hardness related to height below apex as a curvilinear function with a lower rate of increase at heights farther below the apex. Depressions and minor apices affected integrated Ram hardness; however, the influence was relatively minor at all 3 sampling periods. It appears that integrated Ram hardness at these relatively exposed or sheltered stations was influenced more by differences of relative snow accumulation as opposed to a differential compaction of the snow. It appears that the variables STAH and STBH may have poorly modelled the impact of slope and perhaps depressions/apices on integrated Ram hardness. A separate indicator of slope might have enhanced the predictive capability of the model.

Integrated Ram hardness was greatest within the modified community and similar within the adjacent ridge and fen communities at sampling period 1 (see Temporal and community variation in integrated Ram hardness). It is possible that a quadratic model would have been superior to the power model for integrated Ram hardness and height below apex at this sampling period. A surface crust which had developed by sampling period 3 substantially increased integrated Ram hardness and likely lessened the influence of structural characteristics on this measure of resistance to penetration.

It is apparent that factors other than snow depth influence integrated Ram hardness. The relatively poor relationship between integrated Ram hardness and the structural variables as compared to snow depth and these variables likely reflects a variable influence of wind on the snow across a beach ridge. Snow near the apex of a ridge, although shallow, is subject to greater influence by wind, and is subsequently more wind-packed and likely more dense. This results in integrated Ram hardness values which are relatively high per unit snow depth near the apex leading to a relatively poor relationship between integrated Ram hardness and the physical measures. The results may have been influenced somewhat by deletion of stations from the periphery of the transects.

Influence of aspect and other variables on snow depth and integrated Ram hardness

The potential variable influence of wind on different sides of the

beach ridges (aspect) was hypothesized to influence integrated Ram hardness but this hypothesis was supported at sampling period 1 only. It may be that aspect had only a marginal influence on integrated Ram hardness because an increase in snow depth, on any side, will positively influence integrated Ram hardness. Aspect influenced snow depth; however, this influence at the ends of February and March, while significant statistically, was not significant practically because of the small increase in the coefficient of determination. This suggests that solar radiation and wind did not substantially impact one side of the ridge more than the other. Unfortunately, the analysis was confounded by the fact that beach ridges are oriented in different directions. The analysis was also confounded in that some of these ridges had 2 major apices such that a portion of a ridge could have an aspect, for example, towards the Hudson Bay side while being located on the side of the primary apex opposite Hudson Bay. The ability to predict snow depth and integrated Ram hardness across a beach ridge might have been enhanced by a process of normalization of height for these beach ridges of various heights. Such a procedure would require complete sampling to the base on each side of the ridges.

A number of other variables may have had an influence on snow depth and integrated Ram hardness across the beach ridges. These include distance in the north/south gradient, distance from the coast, height above sea level, orientation, and adjacent vegetation (eg., the presence of coniferous vegetation). These variables were not tested within the regression framework because there are only 6 observations for the 5 variables (i.e., 6 transects). Draper and Smith (1981) suggest that a minimum of 10 observations per independent variable should be available. The proximity of a station to a pond may also have influenced snow depth and integrated Ram hardness although any influence may have been eliminated when stations without values for both relief variables were eliminated.

The relationship between integrated Ram hardness and snow depth

Within the fen community, a weak linear relationship existed between integrated Ram hardness and snow depth at sampling periods 2 and 3. No relationship was apparent at sampling period 1. The relationship was not statistically different between the 2 sampling periods despite a substantial

increase in integrated Ram hardness with a relatively minor increase in snow depth. The lack of a statistical difference likely relates to the relatively small sample size in combination with a relatively poor relationship. The poor relationship at sampling period 3 likely resulted from a strong surface crust which elevated integrated Ram hardness substantially and irrespective of snow depth.

Snow depth and integrated Ram hardness related as a curvilinear function across the beach ridges. The relationship between these variables was not different for sampling periods 1 and 3 despite the presence of a surface crust and considerably greater integrated Ram hardness and snow depth at sampling period 3. This result might have been due to sample size (with respect to intercepts in particular) because predicted Ram values were considerably greater for the relationship for sampling period 3. The relationship at sampling period 2 was different from the other periods with integrated Ram hardness increasing at a slower rate at greater snow depths and the rate of increase being substantially less than unity. In contrast to sampling periods 1 and 3, integrated Ram hardness per unit snow depth decreased with increasing snow depth. This suggests that stations with relatively deep snow may not have been as wind-modified at sampling period 2 as compared to sampling period 1 and that wind had relatively little impact on the snow density between these 2 periods (hence the similar integrated Ram hardness despite a substantial increase in snow depth). The determination of the relationship from <u>different sets (mean and likely range) of the independent variable</u> may have been largely responsible for the different relationships between sampling periods 1 and 2. The different relationship between periods 2 and 3, although potentially influenced by a moderate increase in snow depth within the modified community, likely resulted primarily from the surface crust at sampling period 3.

Integrated Ram hardness was related primarily to snow depth with structural characteristics having little additional influence. Aspect at sampling period 2 and height below apex and aspect at sampling period 3 had an influence and this influence was minor. For a given snow depth, integrated Ram hardness decreased with increasing height below apex, perhaps the result of increased sheltering from wind and/or solar radiation. Height below apex indirectly influenced integrated Ram hardness through its strong

influence on snow depth. Although aspect had an impact on integrated Ram hardness at sampling period 3, it was stations on the Hudson Bay side of the apex which had higher values, not the opposite side as expected (as all transects were oriented west of north). This suggests that solar radiation did not impact integrated Ram hardness differently on the sides of beach ridges (perhaps the finding was the result of structural differences). Integrated Ram hardness may also have been influenced by the underlying vegetation or adjacent plant communities (eg., presence of conifers).

Muskoxen, snow, and other considerations

The authors of most studies acknowledge the importance of nival conditions to muskoxen but provide little data which relates the impact of snow on habitat selection, food habits, distribution, and survival. McLaren and Green (1985) believed that a deep, hard snow cover influenced the availability and use of habitat on Melville Island, N.W.T. during 1982. Miller et al. (1977) related movement and recruitment of muskoxen to unfavourable snow cover and icing conditions on the western Queen Elizabeth Islands, N.W.T. These and other studies typically lack quantitative data which describe the influence of snow on muskoxen (i.e., What constitutes a deep, hard snow cover or unfavourable snow cover?).

Lent and Knutson (1971) observed adult male muskoxen cratering in snow to a maximum depth of 27 cm and a maximum integrated Ram hardness of 370 kg•cm during April 1970 on Nunivak Island, Alaska. They suggested that forage would be available to a depth of 37 cm and an integrated Ram hardness of 570 kg•cm in a second area where muskoxen were feeding upon Elymus mollis and Empetrum nigrum. Muskoxen foraged within sedge habitat during 1969 but restricted their distribution almost entirely to elevated and less productive windswept habitat in 1970. Lent and Knutson (op. cit.) attributed this difference to the formation of ground-fast ice in 1969. Smith (1984) indicated that muskoxen rarely foraged where depths exceeded 30 cm on Nunivak Island. Jingfors (1981) found extensive winter use of riparian willow thickets and riparian Dryas terraces (habitat very similar to our ridge community) along the Sadlerochit River in Alaska. The mean snow depth within the riparian Dryas terrace habitat was estimated at 15.0 cm on 29 October 1978, 20.5 cm on 5 November 1979, and 19.2 cm on 2 April

1979. Thomas and Edmonds (1984) observed muskoxen feeding on Melville Island, N.W.T. within drifts and craters up to 50 cm in depth and digging through the deep (undefined) snow cover in the sedge meadows throughout the winter.

Lent (1971) reported on muskoxen feeding in willow thickets with a snow depth of approximately 30 cm when adjacent upland tundra was relatively snow-free. Rapota (1984) indicated that muskoxen introduced to Taimyr Peninsula, U.S.S.R. grazed tussock tundra until snow depths of 20-30 cm forced them into habitat of poorer quality. Thing (1984) recorded a shift by muskoxen in Greenland from preferred wet meadows to dry upland areas and related this to deep (undefined) snow.

The responses of muskoxen to snow conditions as reported in the literature are somewhat conflicting when snow depth is considered in isolation. The variation in observed response is a result, in part, of the geographical and temporal variation in nival conditions. The selection of foraging sites is a response to both snow depth (and other snow characteristics) and types of habitat available. Within the Manitoba study area, the graminoid-dominated fen community might provide muskoxen with forage adequate to maintain a winter energy balance near zero (Thing 1984). Muskoxen could use plants from the fen (Salix sp., Betula sp.) and ridge (Salix reticulata) communities to meet their nitrogen requirements and might balance nitrogen at the expense of energy during late winter as documented for elk, Cervus elaphus (Hobbs et al. 1981). The selection of one habitat (or several) for foraging is likely a response to a complex interaction between the nutritional requirements of the muskoxen, the ability of a habitat (or habitats) to meet these requirements (the benefit), and the energetic cost of obtaining the forage.

The potential thresholds of 30 cm (depth) and 400 kg·cm (integrated Ram hardness) were selected based upon the previously discussed literature. These thresholds represent potential values as detailed information (muskoxen-snow relationships) necessary to accurately describe thresholds is not available. These potential thresholds are not adjusted for the impact of icing conditions (snow depth threshold) and length of time (i.e., a snow depth of 30 cm for 3 days would produce a less severe impact than a snow depth of 30 cm for 3 months). Thresholds would vary between

habitats and for different age/sex classes of muskoxen. The value 20 cm represents a potential threshold less environmentally stressful to muskoxen. It is important to recognize that the concept of a threshold does not always apply because the response of animals to varying environmental conditions is often one of degree (e.g., Verme 1977, Parker and Robbins 1984).

The mean snow depth was less than the 30 cm potential threshold during some portion of the winter in all communities. Within the fen and modified communities, average snow depth increased from approximately 25 cm at the end of January to approximately 35 cm at the end of February to approximately 45 cm at the end of March. The snow depth within these 2 communities appears to have been reasonable at the end of January but excessive at the ends of February and March on the basis of most available information, the exception being the findings of Thomas and Edmonds (1984).

Snow depths within the ridge community were low at the end of January and averaged approximately 20 cm at the ends of February and March. These depths are comparable to values discussed in the literature and are very similar to those found by Jingfors (1981) for a similar habitat. Snow depths varied between 0 and 65 cm with 53% ≤20 cm at the end of March. The ridge community could serve as a critical area of food availability in the event that muskoxen found nival conditions within the fen and modified communities limiting.

The integrated Ram hardness averaged approximately 300 to 450 kg•cm within the 3 communities at the ends of January and February. These values result from a modified Rammsonde and are slightly inflated; however, the true values would likely have been near the maximum of 370 kg•cm recorded at feeding craters by Lent and Knutson (1971). A reasonable proportion of the stations had values ≤400 kg•cm at these 2 sampling periods. The approximate mean of 900 kg•cm recorded in the fen and modified communities at the end of March is well above defined thresholds. The mean of 571 kg•cm in ridge community was high yet integrated Ram hardness was ≤400 kg•cm at 31% of the stations.

Snow depth varied between 0 and 55 cm and integrated Ram hardness varied between 0 and 1518 kg•cm within a sand dune complex examined by Lent and Knutson (1971) during February. Lent and Knutson (op. cit.) believed that up to one-third of this complex would be unavailable to muskoxen by the

middle of a typical winter. There is similar variability in both snow depth and integrated Ram hardness across the beach ridges examined within the study area. Snow depth and integrated Ram hardness were generally less variable within the fen community as compared to the other 2 communities. The measured variability within all 3 communities at the end of March might allow muskoxen to select relatively favourable sites to forage on a microsite basis similar to caribou (LaPerriere and Lent 1977).

Muskoxen will forage in sites of low snow cover when given the opportunity (Lent and Knutson 1971, Jingfors 1981). Within the study area, mean snow depth and mean integrated Ram hardness appear to have been near or above limits for muskoxen within the fen and modified communities at the ends of February and March. Although means appear excessive, a sometimes substantial proportion of both fen and modified habitats would have been accessible to muskoxen due to the variability in snow depth and integrated Ram hardness which exists within these habitats (eg., 16% of the stations within the fen community had a snow depth $\leq$30 cm at the end of March).

At sampling period 1, recrystallization of snow had resulted in the formation of pukak (the layer of snow nearest the ground described by Pruitt (1978) as that which "consists of interconnected columns of large hollow pyramids") in the fen community. Lent and Knutsen (1971) found that snow did not fully penetrate some of the underlying vegetation at Nunivak Island, Alaska. Muskoxen were observed to access the underlying vegetation by breaking the dense layers of snow into slabs which were pushed away. Jingfors (1981) observed muskoxen to break through a crust by hitting the surface with their chin ("chinning" behavior). The pukak layer might allow muskoxen to forage within the fen community by "chinning" or breaking slabs. The Rammsonde penetrometer might poorly model the energetic cost of such a foraging strategy; however, measures of the cost of such behavior would be required to address this possibility.

It is apparent that the relationship between integrated Ram hardness and snow depth is both complex and dynamic. Lent and Knutson (1971) suggested that snow depth alone would be adequate to predict where muskoxen would feed. The significant temporal variability in the relationship between integrated Ram hardness and snow depth across beach ridges and the weak or non-existent relationship within the fen community

suggests that snow depth by itself would not adequately assess the cost of foraging and therefore the ability of muskoxen to survive and reproduce.

The snowfall at Churchill during 1986/87 averaged 99%, 109%, and 114% that of normal to the end of January, February, and March respectively (Atmospheric Environment Service, Environment Canada). If snowfall within our study area and at Churchill are related, snow depth and integrated Ram hardness at the ends of February and March were likely higher than normal within all 3 communities.

This study provides data from the study area for only 1 year of apparently average or slightly above average snowfall. The extremes of snowfall (and the other variables which modify the snow cover) and the frequency of such extremes may be most critical to the long-term success of a muskoxen transplant. It would be useful to examine snow conditions within the study area for a winter of substantially greater than average snowfall. The length of the winter and the periods of time various depths of snow remain on the ground are likely variables important to muskoxen as found for white-tailed deer, Odocoileus virginianus (Verme 1977). It would be useful to collect data on snow characteristics of potential capture areas to allow comparison of the snow environments between release and capture areas.

It is important to recognize that the findings of this study may have been influenced, perhaps significantly, by weaknesses in sampling. The Cape Churchill Wildlife Management Area General Land Cover Map classified the coastal area as beach ridge complex; however, few beach ridges could be located in the southern 40% of the study area. As a consequence, sampling was not conducted systematically and the sample of beach ridges may poorly represent those within the study area. Although apparently adequate in length when initially set up, data collected during the summer of 1987 indicated that a stable elevation had not been reached and/or the adjacent fen community had not been reached for a number of transects. The consequence of this problem is that sampling was not consistent for each transect (eg., stations sampling the ridge community varied between 26% and 76% of total stations). Slightly different application of the subjective classification of communities (ridge, modified, fen) between transects could also have influenced results. Although these sampling problems may have had some influence on the inferences resulting from the data, the general

lack of large differences between transects suggests that data were reasonably representative.

The Rammsonde penetrometer was used to provide a measure of resistance by the snow column because it was quick and easy to use and offers the potential to measure the energetic cost of foraging. Alternative measures have been suggested to model the influence of snow on muskoxen. These include hardness, thickness, and extent of icing (W.O. Pruitt, Jr., University of Manitoba, pers. commun.), thickness and hardness of hardest layer (B. Hubert, pers. commun.), and depth, density, and hardness (Jingfors 1981).

Willow-dominated habitat within the study area is found as extensive stands (eg., dwarf birch-willow community of Ritchie 1960) and peripheral to ponds and streams. At the first sampling period, portions of some plants (eg., Salix sp., Betula sp., C. aquatilis) extended above the snow cover. Muskoxen will forage extensively on senescent leaves and terminal twigs of willow (Jingfors 1981) although these items may be of poor nutritional quality during the winter (Rapota 1984). The opportunity for muskoxen to use willow-dominated habitat would likely be seriously restricted by the soft, deep (to approximately 1 m) snow found within the willow habitat at the first sampling period. Willow and birch are also found scattered within the fen community and could be utilized by muskoxen, particularly during periods of deep snow when branches would extend above the snow cover.

The beach ridge may also provide habitat important to muskoxen during the spring. Thing (1984) indicated that muskoxen in Greenland foraged during the calving season along a 1-10 degree slope (west-exposed) from which the snow had melted early. Within the Cape Churchill Wildlife Management Area, S. Ransom (Manitoba Wildlife Branch, pers. commun.) observed caribou foraging from sides of ridges where the snow had melted earlier than surrounding vegetation. The earlier exposure of vegetation along the sides of beach ridges might allow muskoxen access to nutritious food at a critical time during their life cycle. The importance of the beach ridge as a critical habitat during both winter and spring would also depend upon the absolute amount of this habitat within the study area.

W.O. Pruitt, Jr. (University of Manitoba, pers. commun.) has

suggested that the maritime climate of the study area could result in ice formation with subsequent forage restrictions and mortality of muskoxen. Ice formation has been indicated as contributing to significant mortality for muskoxen populations (Vibe 1967, Parker et al. 1975, Smith 1984). It might prove useful to examine how frequently ice formation occurs at Churchill while recognizing that wind might have an important positive influence on snow conditions within the study area. Caribou (Rangifer tarandus) presently forage within the study area during the winter, hence it would appear that ice formation is not a serious problem (although caribou can and do utilize the adjacent forest-tundra which might be influenced relatively little by the local climate.

The interrelationships between muskoxen, their nutritional requirements (quality and volume), and the influence of snow on their ability to meet these requirements are only generally understood. An initial objective of this study was to relate biomass (including quality) within the plant communities (fen, modified, ridge) to the energetic cost of obtaining this forage. Although limited data have been collected on species frequency (Rewcastle 1986, Soprovich, unpubl. data), measures of productivity within the fen and across the beach ridges are lacking for the study area. The productivity and quality of plants is important not only as forage during the winter but in their influence on the ability of muskoxen to prepare for the energetic cost of winter (Klein 1970). Productivity is expected to be adequate within the study area; however, productivity data are important to a complete assessment of the suitability of the study area for muskoxen. The collection of productivity data would require significant inputs of time.

Caribou were observed foraging along the beach ridges in the vicinity of the Broad River during August 1987. This species very likely has a significant modifying influence on the vegetation of the beach ridge. The beach ridge at the south end of the study area differed from other ridges examined in that several species of plants reached a height >35 cm (eg., Hedysarum mackenzii). The vegetation rarely exceeded 10 cm within the ridge community on other ridges. This obvious difference could relate to differences in wind speed, snow accumulation, and compaction, or to minimal grazing by caribou in the southern area. It is generally considered that

caribou and muskoxen do not compete for forage during the winter (Thomas and Edmonds 1984) with muskoxen foraging on graminoids and browse (willow) and caribou foraging primarily on lichens. Muskoxen have been observed to utilize lichens (Thing 1984) and Klein and Staaland (1984) have suggested that reindeer may have outcompeted muskoxen on Svalbard Island when on a diet of graminoids and browse. The endemic subspecies of reindeer from Svalbard Island is unique (Klein and Staaland 1984) in that it exhibits morphological, physiological, and behavioral adaptations to its island existence (with an absence of predators and harassing insects, lack of need for migration). The presence of significant numbers of caribou within the study area would likely have some influence on muskoxen; however, this would appear to be minor.

In addition to the poor classification of the southern 40% of coastal area as beach ridge complex with well-defined ridges, the Cape Churchill Wildlife Management Area General Land Cover Map did not document a very large (approximately 1 km in diameter) expanse of willow-dominated habitat in this southern area. It should be noted that the beach ridge complex in the northern portion of the study area is dominated by fen with relatively little area dominated by beach ridges. This observation is consistent with that of Rewcastle (1986) for the beach ridge complex. C. Johnson (nee Rewcastle, Manitoba Wildlife Branch, pers. commun.) indicated that a community dominated by tamarack (Larix larcina) was misclassified by the General Land Cover Map. This information suggests that further ground-truthing is necessary to improving the accuracy of this General Land Cover Map.

It is difficult to assess the potential success of a muskoxen release within the study area given the limited information available upon which to assess the impact of snow and the knowledge that success will relate to factors additional to the snow environment. If we consider snow in isolation, there are plant communities (ridge) and areas within plant communities (microsites) available to muskoxen throughout the winter. However, the snow environment in the study area was less than optimal and could influence the success of a muskoxen release.

RECOMMENDATIONS

1. A release of muskoxen in the study area can proceed on the basis of this examination of snow cover.
2. Future sampling should ensure that transects extend completely across beach ridges until the fen community and a levelling of elevation has been achieved. Transects should be located in summer when it can be determined that this objective is met.
3. In the event that future sampling of beach ridges occurs, a topographic map rather than Landsat imagery should be used as a base map to select ridges.
4. Snow depth and integrated Ram hardness data should be collected on the range from which muskoxen will be obtained to allow comparison to snow conditions from the study area.
5. The collection of additional years of data, particularly for years of exceptionally high snowfall, would be very useful.
6. Snow conditions within other habitats should be assessed (eg., willow-dominated habitat) and additional data from the fen community would be useful.
7. Snowfall data should be compared for Churchill and the range from which muskoxen will be obtained. As well as total snowfall, a snow index similar to the snow component of the Verme Index (Verme 1968) might be constructed (eg., by summation of weekly or monthly cumulative snowfall).
8. The collection of snow characteristics (depth, integrated Ram hardness) from areas near Churchill could be related to snowfall data collected at the meteorological station at Churchill and should be considered. The development of relationships might allow estimation of the long-term suitability of the study area for muskoxen (assuming that the areas near Churchill were representative of the study area). The collection of data near Churchill might allow examination of the early winter and late spring conditions during which travel to the study area is restricted.
9. Additional ground-truthing of the Cape Churchill Wildlife Management Area General Land Cover Map is required to make it more accurate.

10. The collection of data on plant productivity would be useful.

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